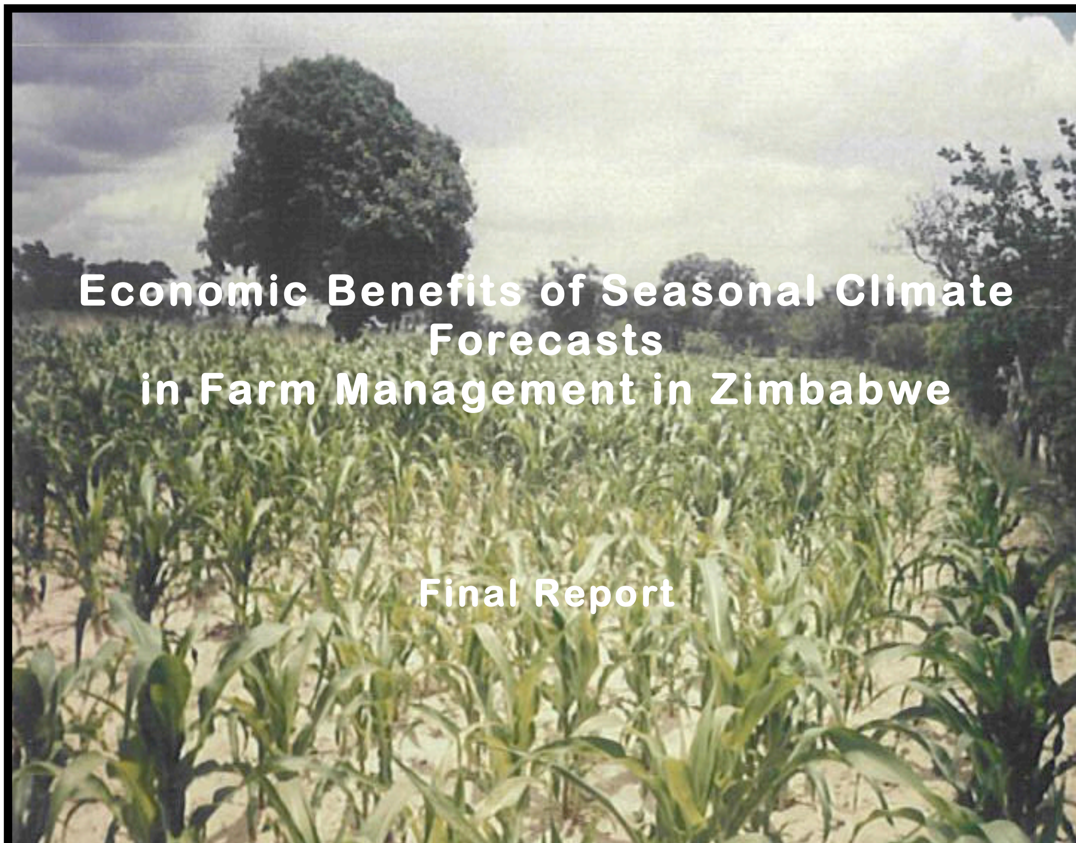
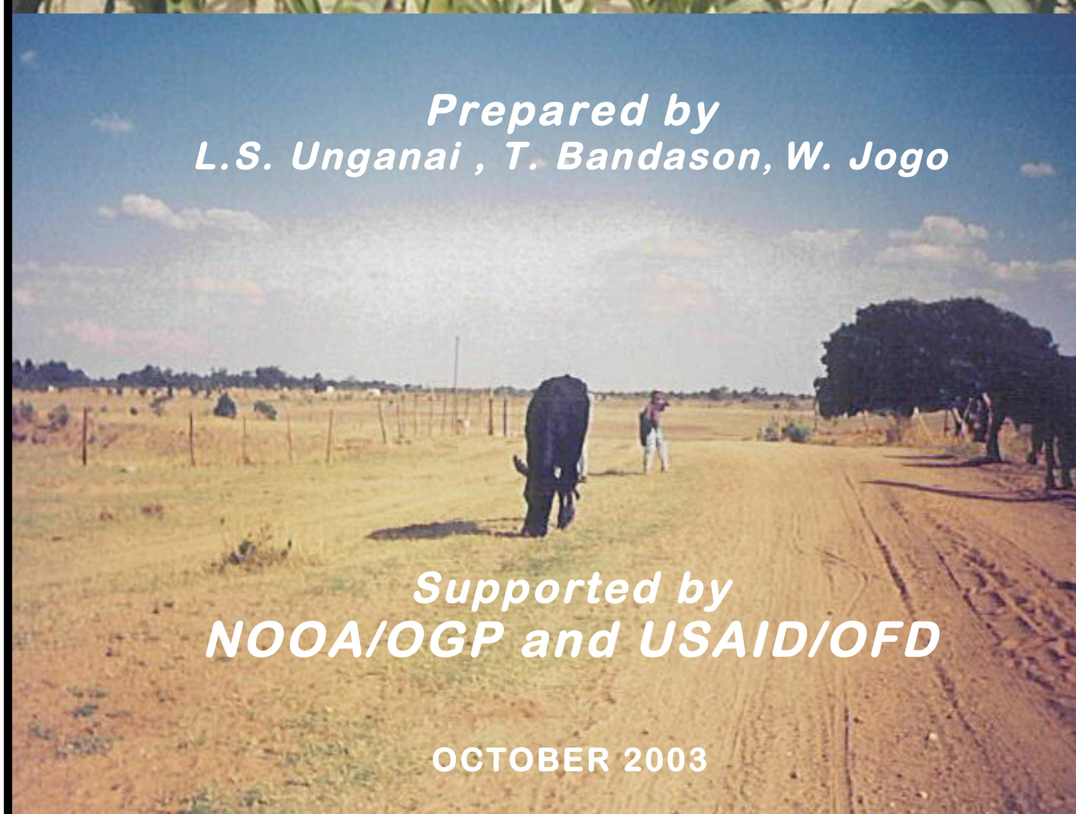


Economic Benefits of Seasonal Climate Forecasts in Farm Management in Zimbabwe

Final Report



Prepared by

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OCTOBER 2003

Abstract

High inter-annual rainfall variability is the major cause of rain-fed crop yield and income fluctuations among smallholder farmers in Zimbabwe. The farmers' over dependence on a single regulated crop, maize (*zea mays*) for livelihoods increase their vulnerability to climatic shocks. Despite recent advances in the seasonal climate forecasting science, managing crop production risks associated with inter-annual climate variability has not yet become a significant feature of the Zimbabwe agriculture system particularly among small-holder farmers. A skillful seasonal forecast within an agricultural systems analytical framework should provide an opportunity for farmers to better tailor cropping systems management decisions to the season ahead. This project aims to:

- Assess the value of applying seasonal climate forecasts in small-holder cropping systems management in Zimbabwe;
- Develop an appropriate operational framework for connecting seasonal climate forecasts with cropping systems management in a variable Zimbabwe climate.

Surveys involving 250 households were implemented in three successive cropping seasons to establish the socio-economic and agricultural systems setting of the smallholder farmers in Zimbabwe. Owing to the complexity of carrying out several on farm trials in several locations, APSIM, a crop simulation model was used to generate data for different cropping systems management and climate scenarios. Climate data spanning the period 1917 to 2002 was obtained from the Zimbabwe Meteorological Services to assess climate risk. For crop simulations daily climatic parameters for the period 1961 to 2002 were used. The Standardized Precipitation Index (SPI) is used to quantify drought patterns at the study sites. The economic value of ENSO based seasonal forecasts is estimated from the difference in gross margins from with and without ENSO information scenarios.

Results from this project confirm that Zimbabwe summer rainfall responds to ENSO phase shifts. Up to 16% of the country's summer rainfall variance can be ascribed to ENSO. The risk of drought ranges from 21 - 40, 16 - 26 and 0 – 22% during the warm, neutral and cold ENSO phases respectively across the country. The influence of ENSO on rainfall varies in both time and space. Rainfall during the October to December period responds to ENSO more than that of January to March. Three drought types affect the country. Type I is characterized with a dry October to December followed with wet conditions in January to March. Type II drought has a wet October to December followed with a dry January to March. Type III drought has poor rainfall throughout the rainfall season from October to March as was generally the case during the 1991-92-rainfall season. It is also shown that the influence of ENSO on rainfall decreases from the southern to the northern sections of the country. These findings have an implication on the application of ENSO based seasonal climate forecasts in agricultural management in Zimbabwe.

Smallholder farmers who adjust their cropping plans in response to ENSO phase shifts stand to benefit in the long-term. Response to the neutral ENSO phase, which has a 51% frequency of occurrence, yields positive economic returns compared with the other phases. The value of ENSO phase information to the smallholder farmer ranges from 10 to 70USD per hectare for selecting optimum maize management strategies during the neutral phase. For cowpea, the value ranges from 10 to 660 USD per hectare. However these estimates are only approximate since only the prices of seed, fertilizer and output were considered in the gross margin calculations. Lack of economic gain during the El Nino phase suggests that resources required to manage drought are significant and generally beyond the means of most smallholder farmers.

Acknowledgements

This project is being carried out with financial assistance from USAID/OFD and NOAA/OGP. Dr John Dimes has provided invaluable modeling guidance. Wellington Jogo has contributed immensely in the simulation work. A number of other experts have assisted greatly with comments and advice on this work.

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Chapter 1

INTRODUCTION

1. 1 MOTIVATION

Zimbabwean farmers operate in a highly unreliable rainfall regime. Up to 70% of the country's population of about 13 million people depend directly on rain-fed agriculture for their livelihood. Two main sources of risk for the farmers are – the recurring cycles of drought and the changing economic value for farm produce in relation to cost of production. Over dependence on a single agricultural commodity for livelihoods expose the smallholder farmers to both production and market risks. The economic benefits of changing farm management strategies given a seasonal climate forecast have not been quantified for Zimbabwe. Despite recent advances in El Nino – Southern Oscillation (ENSO) forecasts, most farmers have not been able to translate the forecasts into better farm management practices to minimize yield losses and maximize profits. It has been demonstrated elsewhere that farmers adopt new technology if that technology has a net positive economic benefit. An effective application of climate information should lead to a change in decision or results in either an economic improvement or a reduction in risk. The objective of this study is to demonstrate the gross margins associated with adjusting crop management strategy given an ENSO based seasonal climate forecast for selected sites in Zimbabwe. More specifically, the study seeks to:

- Determine small-holder farmer risk perceptions and how farm management strategies are arrived at in real life,
- Assess the economic worth of different farm management strategies with or without a seasonal climate forecast,
- Come up with an appropriate operational framework for the packaging, communication and application of seasonal climate forecasts for smallholder farm management in Zimbabwe.

The results will find application in justifying further investment in improving seasonal climate forecast science as well as for promoting the uptake of seasonal climate forecasts for rain-fed crop production risk management among smallholder farmers in Zimbabwe.

It has been argued that in regions of the world, such as Zimbabwe, where ENSO is one of the primary influences on inter-annual rainfall fluctuations and in turn crop yields (Janowiak, 1988; Unganai and Mason, 2002), farmers who consistently use seasonal climate forecasts stand to enhance farm management for more stable crop yields and farm income (Phillips et al., 1998). Since little land is irrigated in Zimbabwe, variable rainfall easily translates into variable production levels creating food security problems. The development of computer crop simulation models offer opportunities to add value to ENSO forecasts, by transforming the variable rainfall distribution patterns associated with any seasonal forecast into crop production outcomes for a range of management options. Crop simulation models and field surveys can be used to evaluate the productivity and economic performance of agricultural management options given a particular ENSO scenario. This vital linkage is currently missing in the seasonal climate forecast – farmer decision-making equation thereby limiting the potential application of seasonal climate forecasts in agricultural management.

The first part of the study establishes the context in which the farmers operate in a given region, whereby climatic, production and natural resource variability are described. Risk characterization is achieved in part by analyzing climate records from the Zimbabwe Meteorological Services Department. Structured questionnaires are used to capture demographic data for the selected study sites. Interviews with farmers and published agricultural extension material provide information on standard and recommended climatic risk management strategies respectively. A crop simulation model, the Agricultural Production Systems Simulator (APSIM) is used to evaluate crop yield fluctuation under given ENSO-state climate scenarios.

1.2 PHYSICAL SETTING OF THE STUDY AREA

Zimbabwe lies between 15½º S and 22½ºS and longitude 25ºE to 33ºE (Fig. 1). The country is therefore wholly tropical. The main topographic features of the country are the central plateau (1000-1500 m above mean sea level), which traverses the country along a northeast-southwest diagonal, and the low-lying Limpopo and Zambezi valleys on either side of the plateau. Mean annual rainfall in Zimbabwe ranges from below 600 mm in the south to over 800 mm in the eastern sections of the country. The rainy season stretches from about November to March, when the characteristic configuration of air masses can be distinguished forming part of the Inter-tropical Convergence Zone (ITCZ). Rainfall is more reliable in the northern part of the country (Fig 1.2). Both elevation and geographical position contribute to the gradient in seasonal rainfall, which extends from a maximum in the northeastern high-veld to a minimum in the low-veld in the south and southwest.

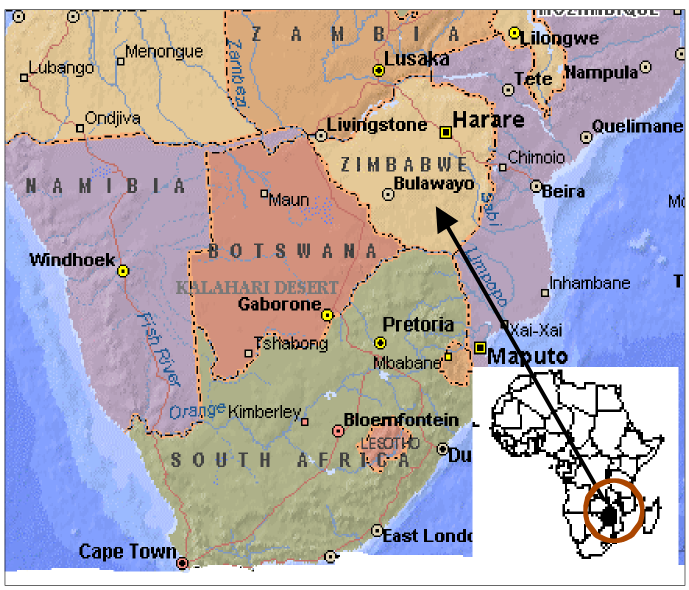


Figure 1. 1 Location Map of Zimbabwe

Agro ecological zones, or "Natural Regions" (NR) defined in the 1960's divide the country into five zones based primarily on seasonal rainfall quantity and reliability, and secondarily on soil type (Vincent and Thomas, 1960). NR 1 is spatially limited to the mountainous areas along the border with Mozambique, and is dominated by plantation crops such as coffee and tea. NRs 2 and 3 are more extensive, with reliable rains averaging 700-1500 mm (NR 2), and 500 to 700 mm (NR 3), and are used for grain and vegetable production. NRs 4 and 5 are considered most appropriate for extensive grazing, with rainfall being less reliable, and averaging less than 500 mm per season. Details on Zimbabwe's agro ecological zones are in Chapter 2.

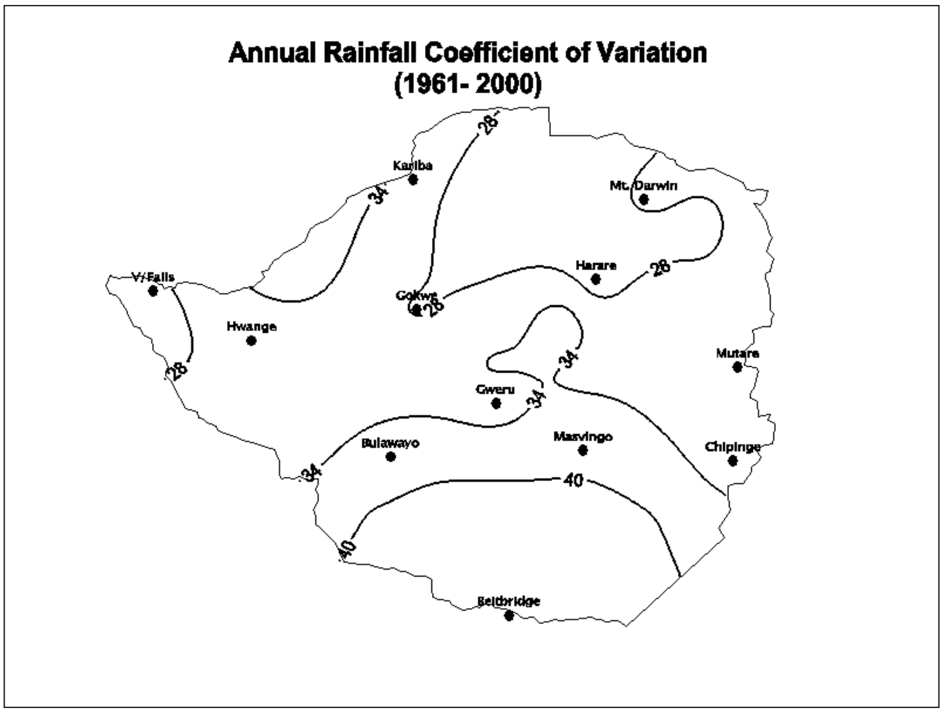


Figure 1. 2 The coefficient of variation of Zimbabwe annual rainfall

1.3 AGRICULTURAL SYSTEMS

The current population in Zimbabwe is about 12 million (FAOSTAT, 1999) with an estimated annual growth rate of over 3%. The annual growth in agricultural output is currently estimated at 2.5%, but fluctuates with weather conditions (Fig. 1.3). Therefore, whereas in years of good rainfall the country produces enough food to feed the nation and enjoys surpluses for export, in years of drought the reverse is the case. Additionally, even in good years many households are not able to grow enough food for home consumption largely because of poverty and because of inadequate access to land. Moreover the little land they occupy is poor land in general.

Zimbabwe's economy is driven by agriculture (Fig. 1.4) and the majority of the rural people depend on it for their livelihood. Moreover, about 80% of the rural population lives in Natural Regions III, IV and V (Scoones, 1996a, 199b) where rainfall is erratic and unreliable, making dry land cultivation a risky venture. The success rate of rain fed agriculture in Natural Regions IV and V has been known to be in the order of one good harvest in every four to five years.

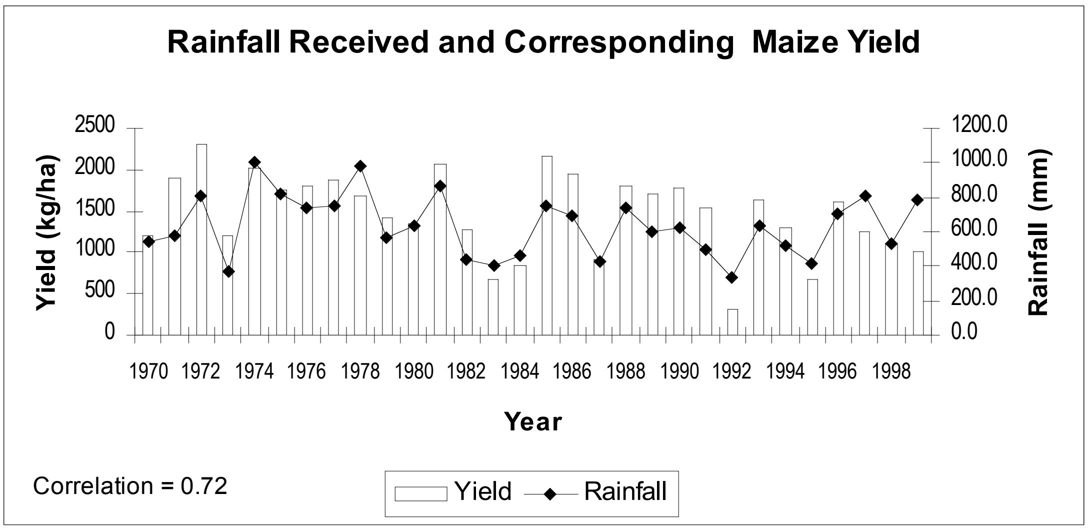


Figure 1. 3 Time series of Zimbabwe smallholder farming sector maize yields and annual rainfall from 1970 to 1999

Land in NRs 1 and 2 is predominantly farmed on a large scale, with a high level of inputs. Yields of rain fed maize (*Zeal mays L.*), the primary crop produced on commercial farms, average approximately 7 t ha^{-1}, comparable to that of developed countries elsewhere. In the smallholder sector, input use is extremely limited, with a very small minority of farmers applying chemical fertilizer, and usually only to maize (Huchu and Sithole, 1994). Some chemical pesticide is used in cotton (*Gossypium hirsutum L.*) production, and is usually distributed in the seed packs made available by the cotton companies who contract farmers to grow it. Tillage is performed with oxen (*Bos taurus*) and weeding is done by hand. Average area farmed per household ranges from about two hectares to approximately five, with the larger holdings in the wetter NRs. Maize is the dominant crop in the wetter zones, while in NR 5 pearl millet (*Pennisetum glaucum L.*), sorghum (*Sorghum bicolor (L.) Moench*) and livestock herding are more important

Components of the farming system Groundnuts (*Arachis hypogaea*) are grown in all zones.

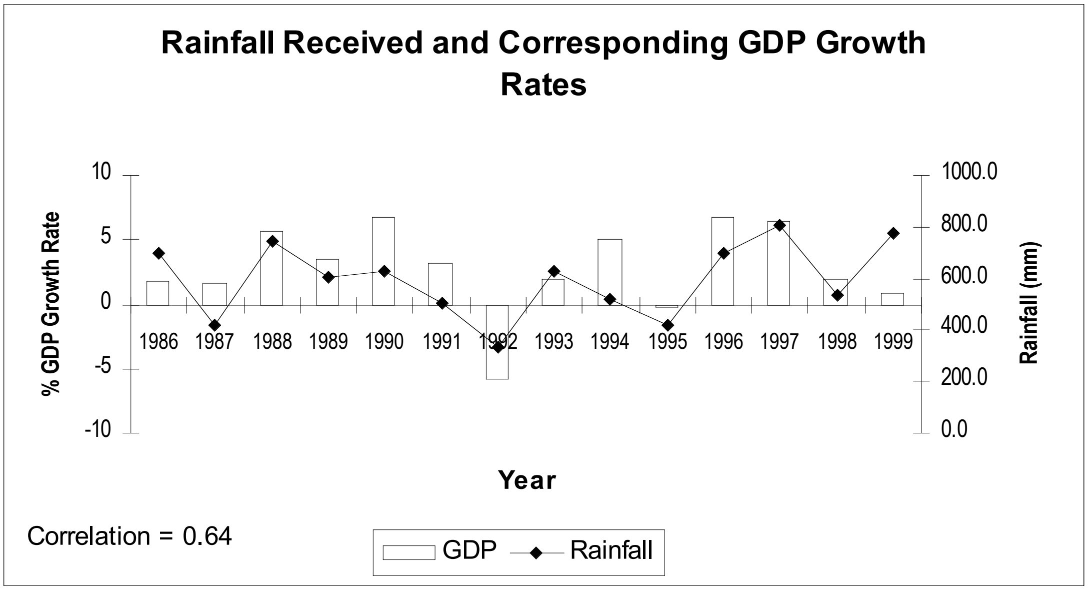


Figure 1. 4 Response of Zimbabwe's GDP growth rate to rainfall

Very few smallholder farmers could be considered purely subsistence farmers, as cash crops such as cotton, sunflower (*Helianthus annus L.*), and tobacco (*Nicotiana tobacum L.*) are grown for income. Women participate in vegetable production or beer brewing from sorghum or finger millet (*Eleusinian coracana L.*) to supplement household income. Additionally, food crops are often sold after harvest when cash is in short supply, sometimes leading to losses if the household runs out of stored grains and has to purchase food before the crop from the following year is harvested. Participation in the cash economy has facilitated the use of purchased crop seed, and virtually all-Zimbabwean farmers use hybrid maize seed. The high use of hybrid maize seed is considered one of the successes of the efforts of the government after independence, and contributed to substantial increases in maize yields in the mid 1980's. The dominant hybrids used are closely related to those introduced in the 1970's specifically for their tolerance of drought and poor soil fertility. Maize yields are typically around 1 to 2 t ha^{-1} on smallholder farmers' fields.

1.4 PREVIOUS WORK

El Nino – Southern Oscillation (ENSO) phase shifts have been found to influence the rainfall pattern in many parts of the globe including Zimbabwe (Ropelewski and Halpert, 1989; Matarira, 1990. Rainfall fluctuations in turn affect crop yield and the general welfare of producers and consumers. Several studies (Solow *et al*. 1986, Chen and McCarl, 1999, Mjelde *et al*. 1996) have estimated the aggregate value to the United States and world economic welfare of farmers adapting to ENSO phase shifts. Substantial gains to producers have also been observed for farm level applications of ENSO information (Marshall *et al*. 1996; Mjelde *et al*. 1997). It has been estimated that use of ENSO information in US agricultural decision-making could result in an economic benefit of 300 to 450 million dollars annually. These estimates suggest that, in those countries where ENSO-rainfall relationships are strong, ENSO phase shifts may have substantial economic consequences for agricultural producers and the country's socio-economic well-being. No previous work has been done in Zimbabwe to establish the economic worth of adjusting farm management strategies given an ENSO based seasonal climate forecast.

1.5 CROP MANAGEMENT

Resource allocation, human goals and decisions constrain crop production at a farm scale. Water allocation and competing land uses are constraints that emerge at regional scales. Hierarchy theory suggests that agricultural systems at increasing scale should become less sensitive to high frequency disturbances such as inter-annual climate variability ().

1.6 THEORETICAL BACKGROUND TO ASSESSMENT OF ECONOMIC BENEFITS OF SEASONAL FORECASTS

Little work has been done in southern Africa to assess the economic value of seasonal climate forecasts largely because experience with climate forecasts is relatively short. Existing economic analysis has been mainly confined to the developed world, particularly

Australia and the United States of America (Arndt, et al., 2000). Studies in South Africa show the relationship between gross income and available water for different crops (Fig. 1.5). Reactions to forecasts can be evaluated at three different scales: micro-economic (e.g. farm), sector (e.g. agricultural sector) and economy –wide. Forecast information interacts with existing policy and reactions to forecasts by different players can aggravate or alleviate existing economic distortions in a country.

To evaluate the economic worth of a forecast at farm level the same climate scenario must be evaluated twice: with and without the forecast or ENSO phase information. Given the without ENSO phase information, producers are assumed to choose a crop plan that represents the most profitable mix across the full spectrum of the period of study. With ENSO phase information, producers are assumed to choose a set of crops that is the best performer economically across that individual ENSO phase. Thus, crop mixes and management strategies, which are optimized for El Nino, Neutral and La Nina events, are selected across a distribution of all the events during the study period. The difference between with and without forecast (ENSO phase information) scenarios is the economic benefit of the forecast (or the cost of ignorance) (Arndt *et al*., 2000). Studying farmer responses to the current seasonal forecasts issued by the Zimbabwe Meteorological Service provide the only basis for analysis. This information is gathered through farmer surveys. Due to very limited empirical experience with farmer reaction to forecast information, simulation modeling of farming systems must play a primary role in assessing value.

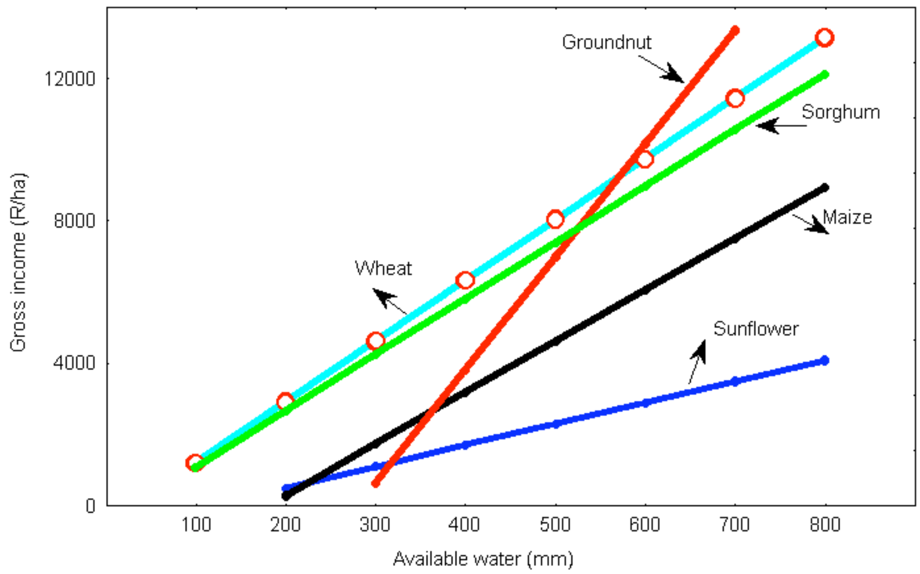


Figure 1. 5 Gross income possible for five different crops at different levels of available water during the season

1.7 HYPOTHESIS

In the foregoing literature review it has been shown that maize yield and farm income are influenced by intra-seasonal and inter-annual rainfall fluctuation. It has further been revealed that that inter-annual rainfall variability in Zimbabwe responds to ENSO phase shifts. A number of efforts aimed at long-range prediction of the country's summer rainfall using ENSO phase shifts or global Sea Surface Temperature anomalies (SSTa) have yielded different levels of success. It has further been argued that maize yields in Zimbabwe can be predicted up to a year in advance from SST anomalies from as far affield as the eastern equatorial Pacific Ocean (Cane, *et al*., 1994).

The hypothesis explored in this study is that smallholder farmers in areas of Zimbabwe where the ENSO signature on inter-annual rainfall variability is strong can realize net positive gross margins from their cropping enterprise by shifting certain crop management strategies according to ENSO phase shifts. It is assumed that the following management strategies offer potentially the best response to ENSO phase shifts:

- Adjustment of planting window,
- Adjustment of Nitrogen management,
- Adjustment of plant density
- Adjustment of row spacing
- Varying crop choice/mix and
- Varying cultivar choice.

The scientific questions asked are:

1. How does the ENSO signal influence seasonal rainfall amounts and intraseasonal distribution at the selected study sites?
2. What are the main features and risk profile of the smallholder farming communities in Zimbabwe in relation to application of seasonal forecasts?
3. What is the current status of seasonal forecasts in Zimbabwe and how credible are the forecast products?
4. What crop management strategies can be effectively guided by seasonal climate forecasts?
5. Is there any long-term economic benefit if a smallholder farmer consistently adjusts crop management strategies in response to ENSO phase shifts?

1.8 SYNTHESIS

In this chapter the relationship between Zimbabwe grain crop production and inter-annual rainfall variability has been shown to be significant to justify changes in farm management practices given reliable seasonal climate forecasts. The theoretical basis for assessing the economic worth of seasonal climate forecasts at farm level has been reviewed. In the next chapter, the data and methodologies used to test the study hypothesis are presented.

Chapter 2

DATA AND METHODOLOGY

2.1 INTRODUCTION

In the previous chapter a review of the theoretical basis of assessing the economic benefits of seasonal forecasts was presented. In this chapter the data used to determine the economic worth of different farm management strategies given the state of ENSO are described. The parameters used include daily values of rainfall, maximum and minimum temperature, and radiation, district crop yields, soil data, prices for seed and fertilizer, and demographic data. Data was obtained from official sources as well as field surveys. Crop simulation modeling provided a large amount of crop yield data in retrospect, which would otherwise be impossible to obtain from official sources and field surveys. There are many gaps in historical data in Zimbabwe particularly on crop production and climate parameters. The sampling frame in this study has largely been constrained by the availability of continuous climate data. The sections that follow describe the data used in more detail.

2.2 STUDY SITES

An agricultural system analysis based on interviews with a sample of 400 households in the Mhondoro and Serima communal lands (Fig 2.1a) was carried out.

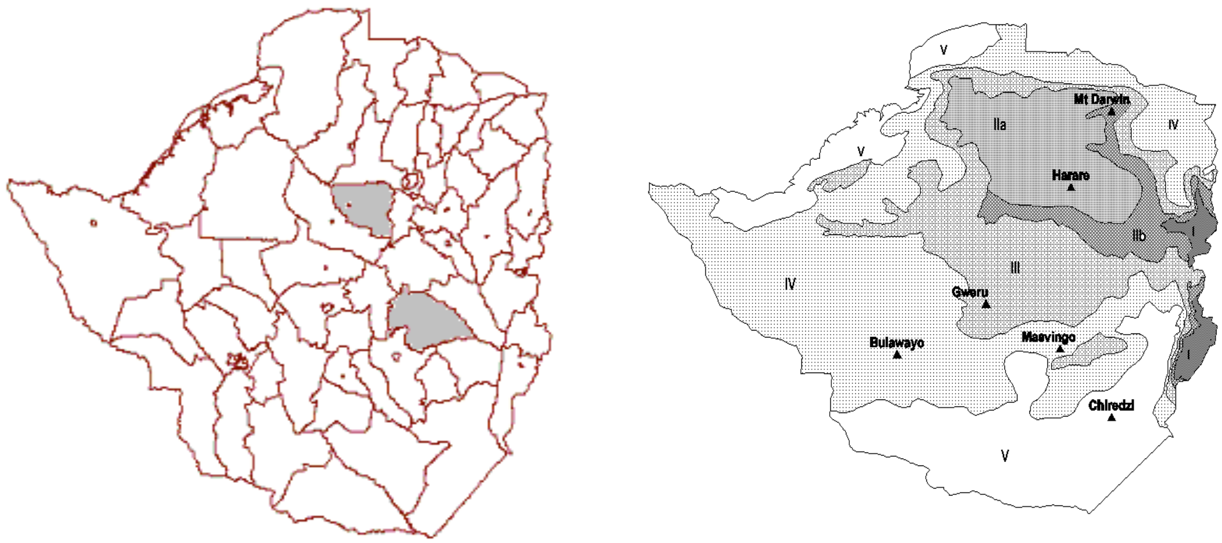


Figure 2. 1a Location of map for Field survey and Figure 2 2b Location of map for simulation experiments

Two hundred (200) households in each area were selected for the study into two categories of wealth (poor and rich). The wealth status was determined on the basis of community wealth ranking.

In order for a region to be considered for a demonstration project on the application of climate information, there must be adequate historical records to support basic analyses of the relationship between climate and agricultural production in the area. This cannot be true for both Mhondoro and Serima. As a result, sites with reliable and long historical climate and district crop yield records were selected for simulation and follow-on demonstration projects. The sites, which span Zimbabwe's Natural Regions II to V, are shown in Figure 2.1(b). The general agricultural and climatic characteristics of the Natural Regions are summarized in Table 2.1.

Table 2. 1 General characteristics of Zimbabwe's Natural Farming Regions

Natural Region	Type of farming	Climatic characteristics
I	Specialized and diversified	Highveld, cool and wet. >1000 mm per annum.
II	Intensive	Highveld, cool and wet summer. 750-1000 mm per annum.
III	Semi-intensive	Medium veld, warm, moderate rainfall. 650-800 mm per annum. Subject to seasonal drought.
IV	Semi-intensive	Lowland plains, low rainfall. 450 – 600 mm per annum. Prone to frequent droughts.
V	Extensive	Low lying valleys. High temperatures. Very low and erratic rainfall. < 400 mm per annum. Northern lowveld may have more rain but the topography and soils are poorer.

2.3 CLIMATE DATA

Meteorological parameters used in the study include daily values of rainfall, maximum and minimum temperature, and radiation. All the data was extracted from the Zimbabwe Department of Meteorological Services CLICOM database for the period 1951 to 2001. Before archiving the data, the Meteorological Services subjects all climatic records to WMO recommended quality control procedures (WMO, 1986). However, given the highly variable nature of convective rainfall in space the results obtained in this study may not be applicable beyond the study sites. Six sites (Fig. 2.1) are used for the study. All the stations used had more than 90% of the records for all the parameters (Fig. 2.2).

Missing values are estimated using the long-term average for that month for rainfall and temperature, whereas for radiation the Black (1956) formula is used (Esq. 2.1):

$$G=G_o(a+b*C+c*C^2) \tag{2.1}$$

Where G_o is radiation at the top of the atmosphere, a= 0.803, b=-0.340, c=-0.458 and C is Mean cloudiness in tenths.

Where sunshine hours are available these are converted to radiation through the Angstrom () formula:

$$\frac{Q}{Q_A} = a + b\cos\phi\frac{n}{N} \qquad 2.2$$

where Q is the amount of radiation received at ground level,

Q_A is the amount of radiation at the top of the earth's atmosphere

b is a constant, usually accepted as 0.52.

Φ is latitude of the station.

n is the number of hours of sunshine received, and

N is number of hours of daylight.

2.4 ECONOMIC DATA

Seed Co provided data on hybrid seed prices for the period 1962 to 2002 for short and long season varieties. The movement of seed prices was checked by government imposed price controls in 1989, 1990 and 2001 (SEEDCO, personal communication).

2.5 FIELD SURVEYS

Understanding the agricultural system and the farmer's operating environment is the first step towards formulating appropriate risk management strategies. Because of geographical differences in soil, climate and farmers' attitude towards risk and their ability to manage risky situations, risk management strategies cannot be generalized even in the same Natural Farming region. The conceptual framework in Figure 2.2 was used to study the smallholder farmer's decision-making environment using a case study approach with the Buhera, Serima and Mhondoro communal lands.

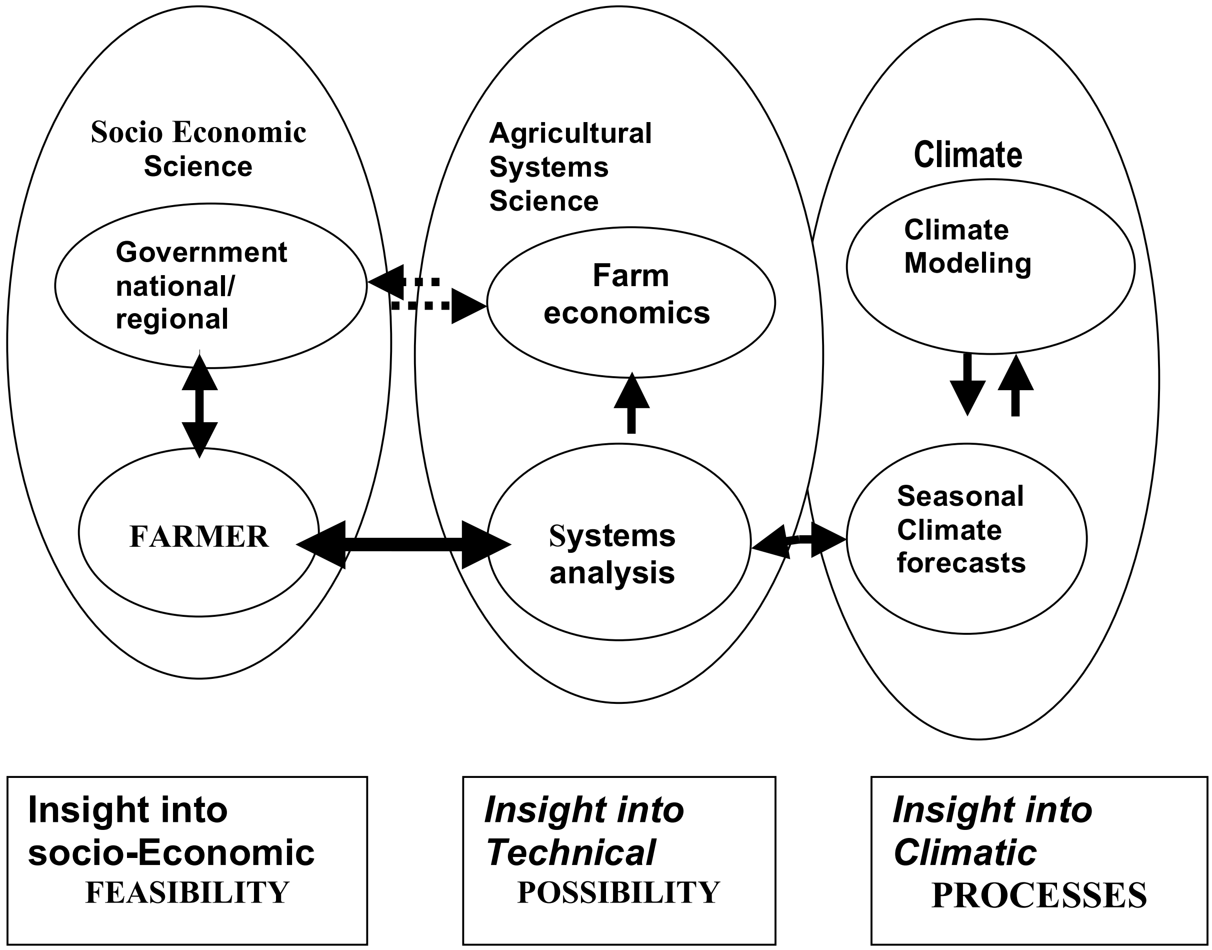


Figure 2. 2 Conceptual frameworks for small-hold farming system analysis

2.6 CROP SIMULATIONS

The Agricultural Production Systems Simulator (APSIM) is used to evaluate the impact of different management options on crop yield and profitability of a given enterprise. Key management options examined include: site, crop, cultivar, sowing window and Nitrogen Management. The conceptual framework used for the simulation experiments is in (Fig 2.3). Details on APSIM are in McCown *et al. (1996).* APSIM is a cropping system simulation model that can predict and evaluate the dynamics of soil condition and crop production while allowing management intervention through tillage, weeding, irrigation and fertilizer application as well as choice, timing and sequencing of crops in fixed or flexible rotations (Meinke *et al*. 2000).

APSIM places equal emphasis on soil and crop aspects and incorporates a flexible system to integrate system management decisions. A number of crop modules and management routines are built into the software. For the purposes of this study, the maize, cowpea, sorghum and groundnut modules are used. In addition to management and soil type information, APSIM uses daily values of maximum and minimum temperature, rainfall and solar radiation to assess production. The advantage of crop simulation over field data collection is that one is able to generate data for a sufficiently long period from which statistically robust conclusions can be drawn. It also eliminates subjectivity and unreliable data usually collected through field surveys.

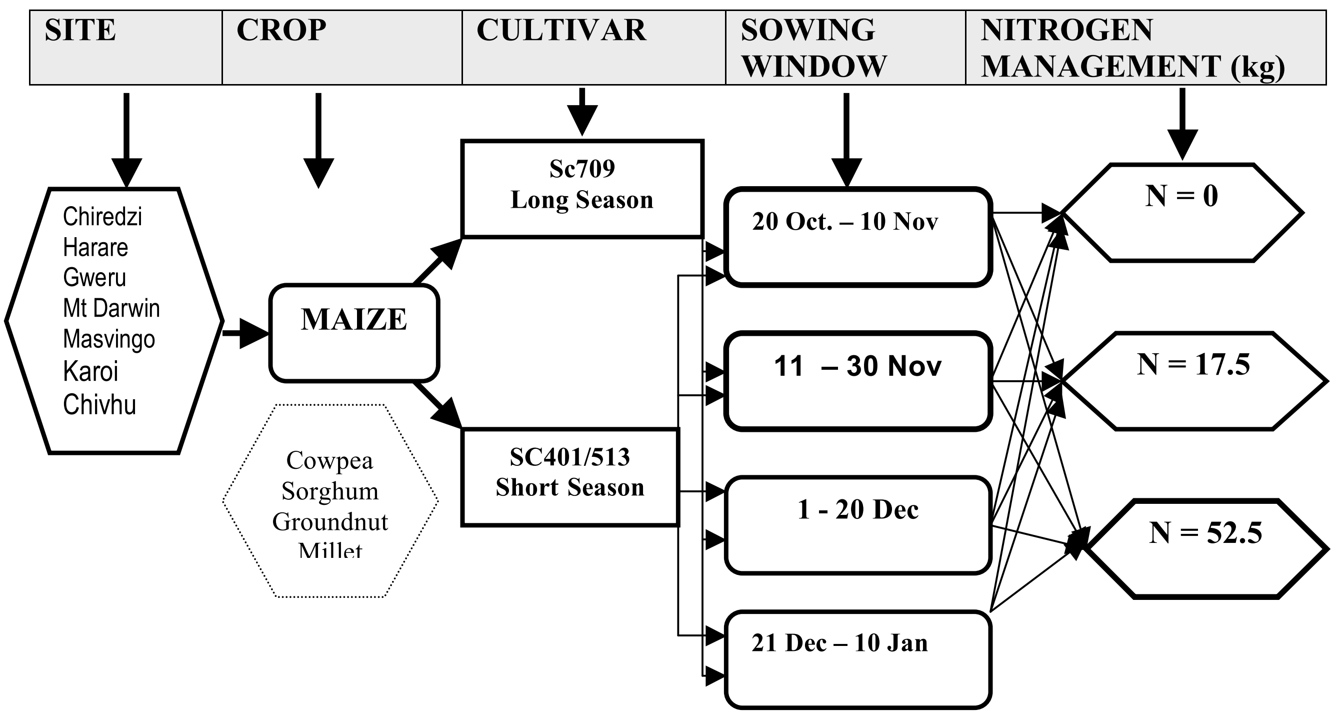


Figure 2. 3 Conceptual frameworks for crop simulations

The availability of good quality input data and coarse spatial coverage are the most serious practical constraints to application of crop models. The spatial aggregation problem is such that crops are produced in an environment that varies both in space and in time. Scaling up model outputs entails applying models that assume a homogeneous environment (i.e. a point in space) to larger areas that can encompass a considerable range of spatial variability. Crop yields at a particular point in space vary from season to season primarily because of the temporal variability of weather. Even if the locations are truly representative, yields simulated at representative locations will not generally represent either the spatial average or the interannual variability of regional yields because of the aggregation error.

2.6.1The Standardized Precipitation Index (SPI)

The Standardized Precipitation Index (SPI) has been developed for the purpose of defining and monitoring drought (McKee *et al*. 1993). The nature of the SPI allows one to determine the rarity of a drought or an anomalously wet event at a given location for a particular time scale. Computation of the SPI involves fitting a gamma probability density function to a given frequency distribution of rainfall totals for a station. The alpha and beta parameters of the gamma probability density function are estimated for each station for each time scale of interest (e.g. 3 months, 6 months, 12 months, 48 months, etc.) and for each month of the year. The maximum likelihood solutions are used to optimally estimate α and β as:

$$\alpha = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right)$$

$$\beta = \frac{\chi}{\alpha}$$

Where:

$$A = \ln(\chi) - \frac{\sum \ln(\chi)}{n}$$

n = number of rainfall observations.

The resulting parameters are then used to find the cumulative probability of an observed rainfall event for a given month and time scale at a particular station.

Since the gamma function is undefined for x=0 and a rainfall distribution may contain zeros, the cumulative probability becomes:

$H(x) = q + (1 - q)G(x)$

Where q is the probability of a zero. If m is the number of zeros in a rainfall time series, Thom (1966) states that q can be estimated by m/n. Tables of the incomplete gamma function are then used to determine the cumulative probability $G(x)$. An analytic method (McKee *et al*. 1993) is used together with suggested software code from Press *et al*. (1988) to determine the cumulative probability.

The cumulative probability, $H(x)$, is then transformed to the standard normal random variable Z with mean zero and variance of one, which is the value of SPI. Requiring an index to have a fixed expected value and variance is desirable to make comparisons of index values among different stations and regions meaningful (Katz and Glantz, 1986). The SPI can be computed for any time scale. In this study the SPI is computed for 3 and 6 months time scales for short-term or seasonal drought index. The three month periods used are October, November, December and January, February, March, whereas the six month period is a combination of the two three month periods. These months cover Zimbabwe's unimodal rainfall season. The three-month SPI for December 1991 would have used rainfall total for November through December 1991.

2.7 SYNTHESIS

In this Chapter the data and methodologies used to test the hypothesis and their limitations have been presented. The next Chapter looks at the predictability of Zimbabwe summer rainfall from ENSO phase changes. Knowledge of the ENSO-rainfall relationships at a particular site is important to identify sites where demonstration projects on the application of seasonal climate forecasts have a good chance to succeed.

Chapter 3

THE EL NINO – SOUTHERN OSCILLATION PHENOMENON AND ZIMBABWE SUMMER RAINFALL

3.1 INTRODUCTION

Zimbabwe summer rainfall responds to the El Nino – Southern Oscillation (ENSO) phase shifts (Matarira …,). Up to 16% of the observed variance in the country's inter-annual rainfall can be ascribed to ENSO phase shifts whereas 60 – 70% of the country's major droughts are linked to warm ENSO events (Unganai and Mason, 2002). However, the influence of ENSO on the country's summer rainfall is not homogeneous across the country. To prescribe appropriate farm management strategies at a given site, it is critical to understand the ENSO – rainfall relationship at the site in question. Generalized farm management recommendations for a given ENSO state are not recommended since local variations from one area of the country to another can be significant.

In the previous chapter the data and approach used in this study are described. This chapter explores the influence of ENSO on rainfall at the selected study sites. The main objective of the chapter is to quantify the climate risk associated with ENSO phase shifts at the selected study sites. The results are important to determine those areas of the country where use of ENSO phase shifts to adjust crop management strategies has potential economic value.

3.2 INTER-ANNUAL RAINFALL VARIABILITY

Zimbabwe rainfall exhibits high inter-annual variability with recurrent droughts and floods being a common feature of the country's rainfall pattern. Most of the wet or dry periods are usually less than four years long. The longest period of successive below normal rainfall during the period 1898 to 1988 was six years from 1933 to 1938 (Matarira and Flocas, 1989). The country experienced particularly severe droughts in the 1980s and 1990s (Matarira, 1990; Cane, et. al, 1994; Waylen and Henworth, 1996). Moderate to severe drought affected large sections of the country for successive years from 1981 to 1984 and also during 1986/87, 1991/92 and 1994/95 leading to massive losses in crop and livestock production (Unganai and Kogan, 1998). Major atmospheric circulation changes characterize wet and dry years in the region. Pressure tends to be anomalously low (high) over much of southern Africa during wet (dry) years (Lindesay, 1984; Tyson, 1980, 1981; Harrison, 1984b; Nicholson, 1989; Matarira, 1990; Matarira and Jury, 1992; Rocha and Simmonds, 1997a; Unganai and Kogan, 1998).

Historical rainfall records across the country show spectral peaks in five bands, 2.2-2.4, 2.6-2.8, 3.3-3.8, 5-7 and 17-20 years (Nicholson, 1986; Tyson, 1993; Makarau and Jury, 1997). However, these periodicities show considerable geographical variation. It has been argued that these periodicities in annual rainfall are indicative of the influence of the Quasi-biennial Oscillation (QBO), El Nino-Southern Oscillation (ENSO), periodic sea surface temperature oscillations, the Antarctic circumpolar wave and luni-solar cycles (Nicholson, 1986; Tyson, 1986; Nicholson and Entekhapi, 1987; Makarau and Jury, 1997).

Southern Africa summer rainfall variability has been generally linked to the El Nino – Southern Oscillation (ENSO) phenomenon (Ropelewski and Halpert, 1987; Lindesay, 1988; Nicholson, 1986; Rocha and Simmonds, 1997a). The main features of ENSO have been described by a number of authors (Rasmusson and Carpenter, 1982; Diaz and Markgraf, 1992). A strong association between Zimbabwe corn yields produced under rain-fed conditions and sea surface temperature anomalies in the eastern equatorial Pacific has been shown (Cane, et. al, 1994), suggesting a strong influence of ENSO on Zimbabwe rainfall. During warm ENSO events predominantly dry conditions occur across much of Zimbabwe with the southeast sections of the country being the worst affected (Matarira and Jury, 1992). However, its not every warm ENSO that brings severe drought as was observed during 1977/78 and more recently in 1997/98. While southern Zimbabwe and Namibia experienced drought during 1997/98, most of southern Africa enjoyed normal rainfall amounts for the season despite a poor start to the summer season (Cook, 2000).

3.3 DATA AND METHODOLOGY

The limited length and gaps in geophysical datasets are often a major constraint in empirical studies. Where two independent parameters or more are used jointly, the quality and length of record of one of the parameters determine the sample size used in the analysis.

3.3.1 Rainfall data

Monthly rainfall data spanning the period 1916/17 to 2000/2001 for each study site is aggregated to yield October, November, December (OND), January, February, March (JFM) and October to March rainfall totals. All the six stations used had complete records. The Department of Meteorological Services made national average rainfall available for the period 1900/01 to 2002/2003 for an assessment of the country's major droughts.

3.3.2 El Nino – Southern Oscillation (ENSO) data

Monthly Southern Oscillation Index (SOI) values for the period 1916 to 2001 were extracted from the Australian Bureau of Meteorology database, whereas the history of El Nino was extracted from the NCEP, USA archive. The SOI was classified into low (warm ENSO), neutral and high phase (cold ENSO) when the SOI during July, August and September (JAS) was below –0.6, -0.6 to +0.6 and greater than +0.6 respectively. Gaps in the SOI during JAS during one of the years were filled in using the ENSO phase as a proxy.

3.3.3 Climate risk assessment

The rural poor in Zimbabwe are exposed to many risks, most of which they are ill equipped to deal with. Drought is one such risk whose impacts on livelihoods can be devastating. Quantifying the level of drought risk associated with ENSO phase shifts is the first step towards formulating appropriate intervention strategies to manage the risk. Rainfall records provide useful information n agriculturally relevant droughts and can be used to assess the risk of drought under given ENSO conditions. In this study, agriculturally relevant past droughts are defined on the basis of farmer perceptions, percent ranking and the Standardized Precipitation Index (SPI).

Based on discussions with smallholder farmers interviewed during field surveys conducted during 1999 and 2000, an agriculturally significant drought would be any event in which the rainfall amount or behavior is similar to or worse than that of 1946/47 or 1991/92. In this study, Using percent ranking of national average annual rainfall totals for the period 1900 to 2002, agriculturally relevant droughts have been defined as those falling within the driest 20% of the years since 1900.

3.3.4 Standardized Precipitation Index (SPI)

The Standardized Precipitation Index (SPI) was developed for the purposes of defining and monitoring drought (McKee *et al*., 1993). The SPI allows one to determine the rarity of a drought or an anomalously wet event at a particular time scale for any location that has a sufficiently long rainfall record. The spatial and temporal dimensions of drought create problems in generating a drought index because not only must an anomaly be normalized with respect to location, but the anomaly must also be normalized in time if it is to produce a meaningful estimate of drought. The SPI achieves both (Akinreni, *et al*., 1996). The SPI was evaluated for some of the stations for OND, JFM and the six months stretching from October to March.

The classification values for SPI values are shown in Table 3.1.

Table 3. 1 Classification of SPI values

SPI Value:	Drought Category:
2.00 and above	Extremely wet
1.50 to 1.99	Very wet
1.00 to 1.49	Moderately wet
-0.99 to 0.99	Near normal
-1.00 to -1.49	Moderately dry
-1.50 to -1.99	Severely dry
-2.00 and less	Extremely dry

Using the SPI approach a drought event is defined as when the SPI is continuously negative and reaches a value of -1.0 or less, and continues until the SPI becomes positive.

3.3.4 Correlation analysis

Time lagged monthly SOI values were correlated with OND, JFM and October to March rainfall at eight stations to assess the strength of the ENSO – rainfall association in different geographical regions of the country. A grouped frequency distribution for each ENSO state and rainfall category is computed at each station to quantify the risk of drought. The threshold of the correlation coefficient that is statistically significant at each station is estimated from:

$$t = \frac{1.96}{\sqrt{N}}$$

3.4 RESULTS AND DISCUSSION

3.4.1 Drought risk

From 1917 to 2002 the warm ENSO phase occurred 28% of the times, neutral phase 51% and the cold episode 21%. During warm ENSO conditions, the risk of total rainfall for

October to March falling into the driest 20% of the years increases up to about 21 and 40% in the north and south of Zimbabwe respectively. On the other hand the cold ENSO episode is associated with an increased chance of wet conditions of around 56 and 80% for the northern and southern sections of the country respectively (Table 3.2). On a national average, the 1991-92 rainfall season ranks as the worst drought to have affected Zimbabwe, followed closely with the meteorological droughts of 1946/47, 1972/73, 1921/22, 1915/16 and 1923/24 in that order of severity (Table 3.3). Of the ten worst droughts recorded from 1900 to 2002 it can be confirmed that seven coincided with the occurrence of warm ENSO events (Table 3.3).

Table 3.2a Frequency analysis of rainfall rank during October-March for the three ENSO States

Site	Enso State	% Proportion of Years- Oct. to March Rainfall Ranks			Number of events	Total years
		<=20%	21% - 60%	>60%		
Beitbridge	Cold	13	13	75	16	
	Neutral	17	46	37	41	
	Warm	36	41	23	22	79
	Cold	22	22	56	18	
	Neutral	16	44	40	43	
Bulawayo	Warm	29	42	29	24	85
	Cold	17	0	83	6	
Chiredzi	Neutral	16	47	37	19	
	Warm	40	40	20	10	35
	Cold	17	11	72	18	
Chivhu	Neutral	16	49	35	43	
	Warm	29	42	29	24	85
	Cold	6	33	61	18	
Gweru	Neutral	19	37	44	43	
	Warm	33	33	33	24	85
	Cold	11	33	56	18	
Harare	Neutral	21	40	40	43	
	Warm	29	33	38	24	85
	Cold	0	33	67	18	
Masvingo	Neutral	21	42	37	43	
	Warm	38	38	25	24	85
	Cold	0	44	56	18	
Mt. Darwin	Neutral	26	35	40	43	
	Warm	21	38	42	24	85

To gain a better insight into the temporal dynamics of Zimbabwe's drought patterns, the rainfall season was split into two parts, October to December and January to March. It is established that, during warm ENSO conditions, the risk of rainfall being in the drought category at the study sites increases from about 21 to 42% during OND depending on the site. The highest increase of 42% is at Gweru and Beitbridge, whereas the lowest increase of 21% is at Mt Darwin to the north of the country. During JFM, the warm ENSO episode increases the chances of rainfall being in the lowest 20% of the years by between 9 and 38%. Beitbridge, Harare, Mt Darwin and Gweru have a 29% risks, Bulawayo, 9%, Chivhu, 33%, Chiredzi 36% and Masvingo 38%. During the cold ENSO events the chances of wet conditions during JFM increase to about 50 to 67%. The highest chance of 67% is at Gweru followed with 61% at Masvingo and Beitbridge. From the foregoing, it can be concluded that warm ENSO conditions increase the risk of drought during both OND and JFM although the risk is higher during OND than JFM at most sites (Table 3.4a and b).

Table 3.2 b Frequency analysis of rainfall rank during October-December for the three ENSO States

Site	Enso State	% Proportion of Years- OND Rainfall Ranks			Number of Events	Number of years
		<=20%	21% - 60%	>60%		
	Cold	6	39	56	18	
	Neutral	18	45	36	44	
Beitbridge	Warm	42	25	33	24	86
	Cold	0	38	63	16	
Bulawayo	Neutral	24	38	38	42	
	Warm	32	41	27	22	80
Chivhu	Cold	6	33	61	18	
	Neutral	18	39	43	44	86
	Warm	29	42	29	24	
	Cold	0	50	50	6	
	Neutral	20	45	35	20	
Chiredzi	Warm	40	20	40	10	36
	Cold	11	22	67	18	
	Neutral	11	52	36	44	
Gweru	Warm	42	25	33	24	86
	Cold	6	39	56	18	
Harare	Neutral	25	39	36	44	
	Warm	29	38	33	24	86
	Cold	0	33	67	18	
	Neutral	20	43	36	44	
Masvingo	Warm	38	33	29	24	86
	Cold	11	39	50	18	
Mt. Darwin	Neutral	20	41	39	44	
	Warm	21	38	42	24	86

Table 3.2c Frequency analysis of rainfall rank during January-March for the three ENSO States

Site	Enso State	% Proportion of Years- JFM Rainfall Ranks			Number of events	Number of years
		<=20%	21% - 60%	>60%		
	Cold	22	17	61	18	
	Neutral	23	40	37	43	
Beitbridge	Warm	29	29	42	24	85
	Cold	13	31	56	16	
Bulawayo	Neutral	30	35	35	43	
	Warm	9	55	36	22	81
	Cold	17	33	50	6	
Chiredzi	Neutral	16	42	42	19	
	Warm	36	36	27	11	36
	Cold	17	28	56	18	
	Neutral	21	40	40	43	
Chivhu	Warm	33	33	33	24	85
	Cold	17	17	67	18	
	Neutral	23	37	40	43	
Gweru	Warm	29	38	33	24	85
	Cold	17	33	50	18	
Harare	Neutral	21	37	42	43	
	Warm	29	42	29	24	85
	Cold	11	28	61	18	
	Neutral	23	40	37	43	
Masvingo	Warm	38	38	25	24	85
	Cold	0	50	50	18	
Mt. Darwin	Neutral	19	42	40	43	
	Warm	29	29	42	24	85

Table 3.3 Ten driest years during the period 1900 to 2002 and the state of ENSO

					SOI before start of season		
Season	Total Seasonal Rainfall	DN	Rank	El Nino	Jul	Aug	Sept
1991/92	335.2	-327.1	0.00	Yes	-0.2	-0.9	-1.8
1946/47	365.2	-297.1	0.01	Yes	-1.1	-0.6	-1.8
1972/73	371.1	-291.2	0.02	Yes	-1.9	-1.0	-1.6
1921/22	385.0	-277.3	0.03	No	0.2	-0.8	0.4
1915/16	394.3	-268.0	0.04	No	-	-	-
1923/24	399.0	-263.3	0.05	Yes	-1.2	-2.0	-1.6
1982/83	403.1	-259.2	0.06	Yes	-1.9	-2.5	-2.0
1967/68	404.8	-257.5	0.07	No	0	0.5	0.6
1994/95	418.8	-243.5	0.08	Yes	-1.8	-1.8	-1.8
1986/87	422.4	-239.9	0.09	Yes	0.1	-1.0	-0.6

3.4.2 *ENSO – rainfall correlations*

The average Southern Oscillation index during July, August and September correlates negatively with Zimbabwe summer rainfall. The correlation coefficients range from –0.3 to –0.4 at most of the study sites (significant at 95% level). Rainfall during OND at most sites in the central and southern sections of Zimbabwe have statistically significant correlations with JAS and OND SOI. During JFM the correlations weaken (Table 3.5). These results confirm the findings in the previous section that show a stronger ENSO impact on inter-annual rainfall fluctuation during OND than JFM. However, at Chiredzi the JAS and OND SOI appear to have a statistically significant association with JFM rainfall instead of OND.

Table 3.4 SOI – rainfall correlations at the study sites. Statistically significant (α = 95%) correlations are shaded

JAS SOI Correlations with			
	OND Rain	JFM Rain	Oct-Mar. Rain
Bulawayo	**0.3**	0.1	0.2
BeitBridge	**0.3**	0.1	**0.3**
Chiredzi	0.2	0.3	**0.4**
Chivhu	**0.3**	0.2	**0.3**
Gweru	**0.3**	0.2	**0.3**
Harare	0.2	0.2	**0.3**
Masvingo	**0.3**	0.2	**0.4**
Mt. Darwin	-0.1	0.1	0.2

OND SOI Correlations with			
	OND Rain	JFM Rain	Oct-Mar. Rain
Bulawayo	**0.4**	0.2	0.2
BeitBridge	0.2	0.1	**0.4**
Chiredzi	0.1	**0.3**	**0.3**
Chivhu	**0.3**	0.2	**0.3**
Gweru	**0.3**	0.2	**0.3**
Harare	0.1	0.2	**0.3**
Masvingo	**0.4**	0.2	**0.3**
Mt. Darwin	0.2	0.2	**0.3**

3.4.3.Intra-seasonal rainfall case studies

The previous sections have presented the strength of the influence of ENSO phase shifts on Zimbabwe summer rainfall highlighting the difference between the first and second part of the rainfall season. In this section the decadal rainfall distribution during four recent warm ENSO episodes is presented. The warm ENSO events used are, 1972-73, 1982-83, 1991-92 and 2001-2002. The four events are selected because of the different impacts they had on agricultural production in the country, from severe to moderate. Plots of the Standardized Precipitation Index (SPI) are used to illustrate the dynamics of short-term (3 months) and long-term (6 months) droughts at the study sites.

No two warm ENSO events are likely to produce identical impacts on rainfall at a given location. Before the 1997-98 El Nino event, the 1982-83 El Nino was classified as the strongest ever recorded. However, the 1991-92 warm ENSO event had the most devastating impacts on rainfall and consequently agricultural production in the entire southern Africa region. The 2001-2002 left more than 8 million people in Zimbabwe in need of food aid after massive crop failures despite the year not ranking as one of the 20% driest years. The main difference among the warm ENSO years appears to be the timing and duration of the intraseasonal dry spell.

In 1972-73 and 1982-83 rainfall was generally low throughout at Gweru and Masvingo. During 1982-83 a prolonged dry spell stretching from late December (Dekad 16) to January (Dekad 21) is evident at virtually all the sites (Fig.). Similarly in 1991-92 rainfall tapered off from late December onwards with no rain recorded at all during February at some of the stations particularly to the south of the country. During 2001-2002, excessive rainfall was received during OND, tapering off completely from January onwards in most areas of country. This temporal distribution of rainfall had disastrous consequences for agriculture. From the foregoing it can be concluded that a drought that sets in from late December onwards will produce more devastating impacts than that which is only confined to the early part of the season. Furthermore, a drought characterized with low but regularly distributed rainfall events, as was the case during 1972-73 is less devastating on agriculture.

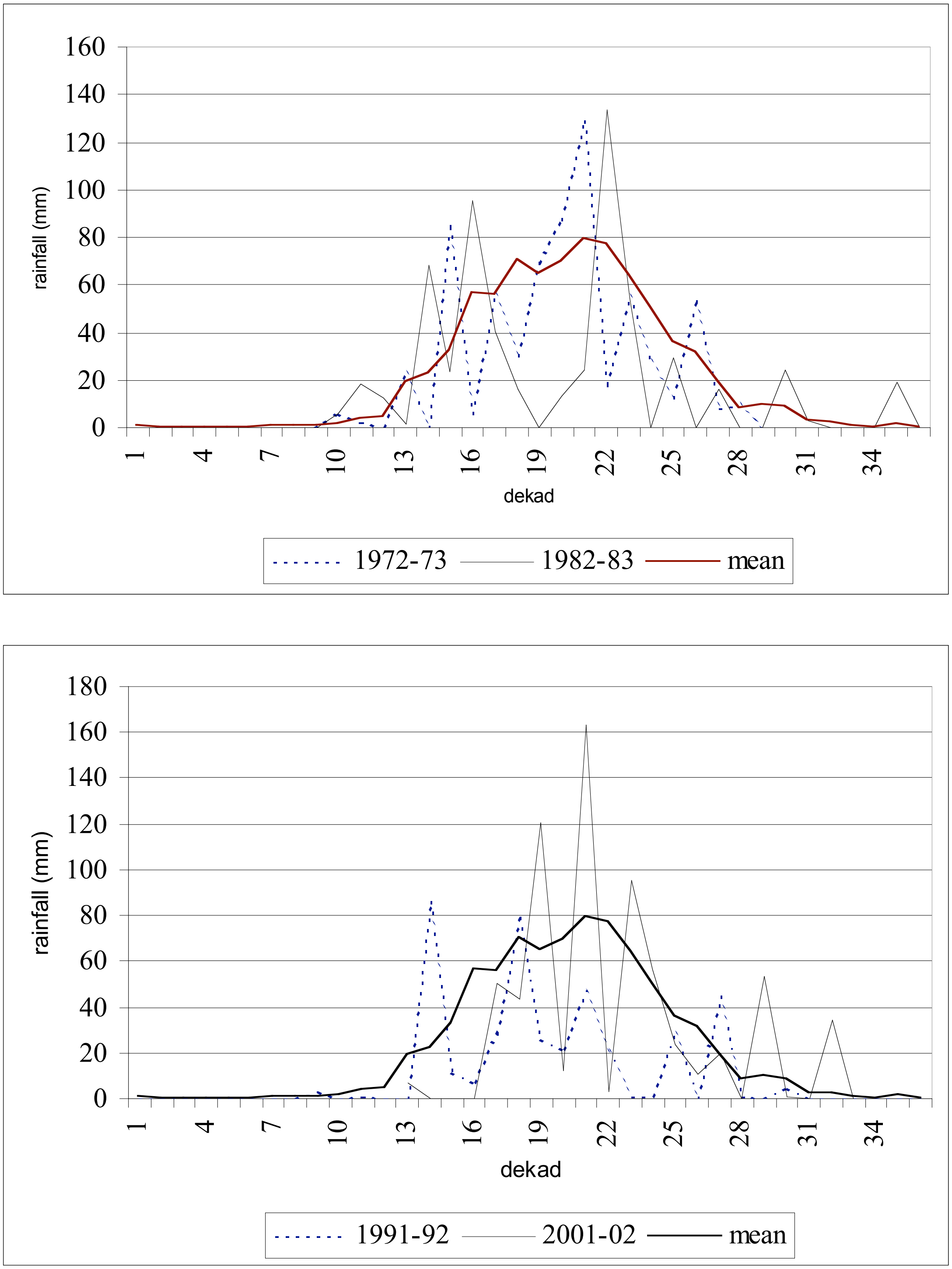
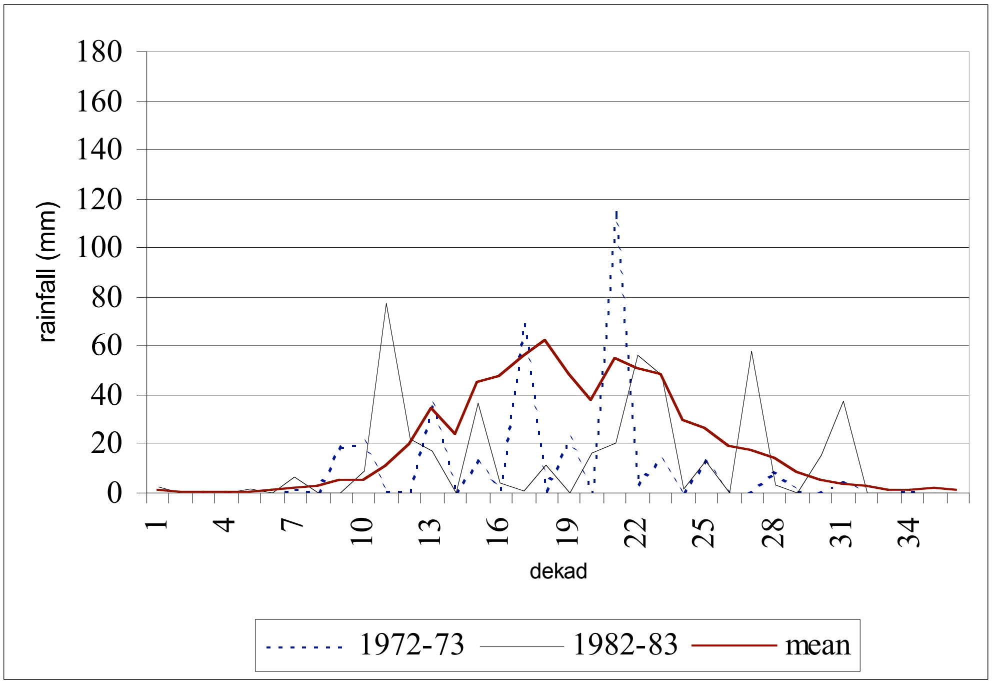


Figure 3. 1a and b – Intra-season rainfall pattern at Mt Darwin during four contrasting warm ENSO episodes [(a) 1972-73 & 1982-83 (b) 1991-92 & 2001-2002]



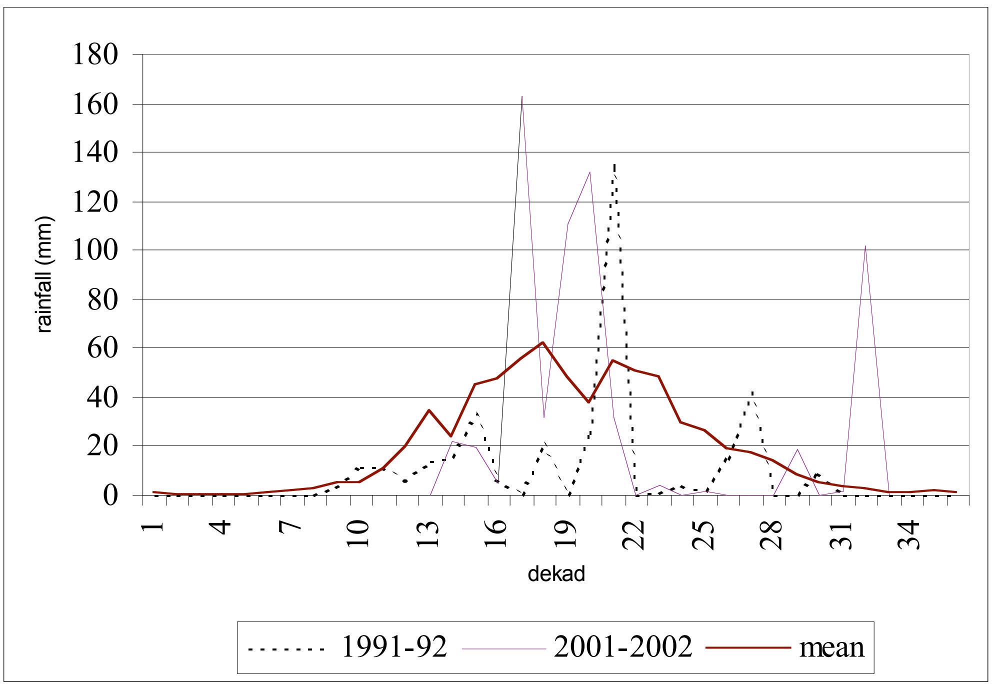
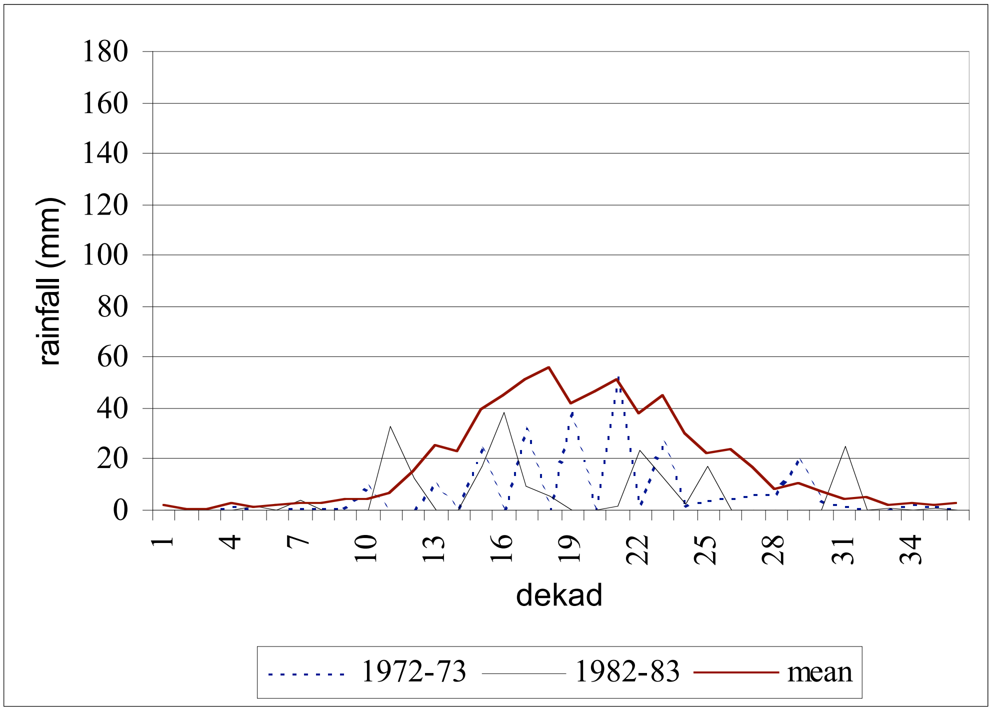


Figure 3. 2 a and b - Intra-season rainfall pattern at Gweru during four contrasting warm ENSO episodes [(a) 1972-73 & 1982-83 (b) 1991-92 & 2001-2002]



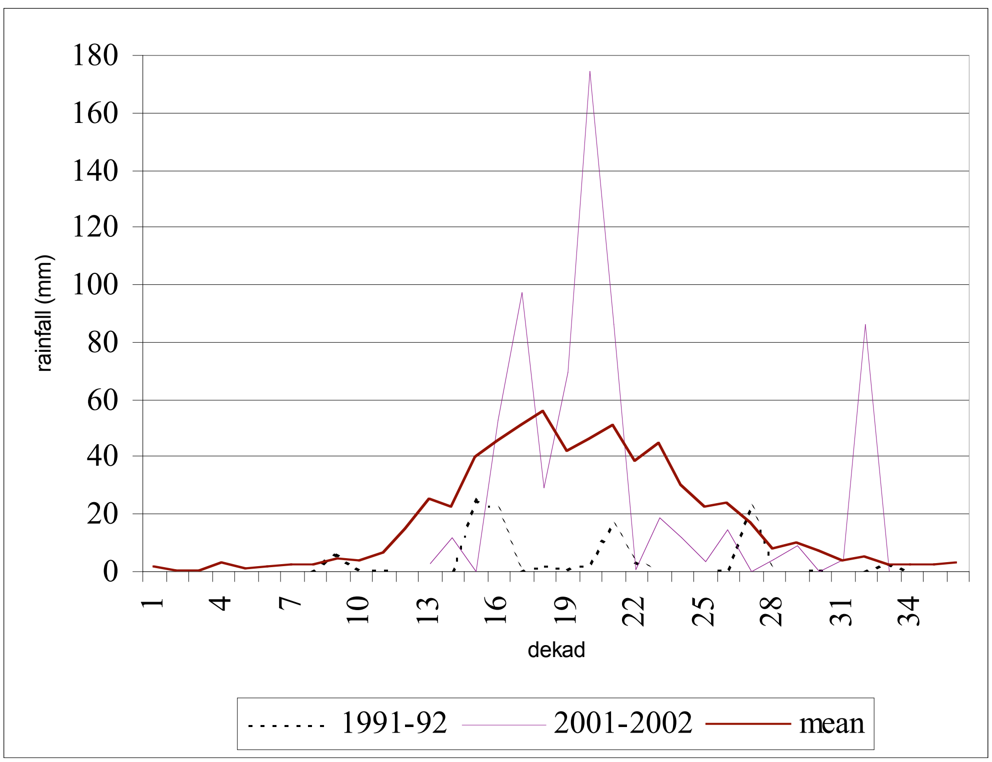


Figure 3. 3 a and b - Intra-season rainfall pattern at Masvingo during four contrasting warm ENSO episodes [(a) 1972-73 & 1982-83 (b) 1991-92 & 2001-2002]

The SPI for Mt Darwin, Gweru and Masvingo confirm that most of the droughts affecting Zimbabwe are short term and usually confined to the first or second part of the season (Fig 3.1 – 3.3).

Table 3.5 Frequency of drought conditions (SPI < –1.0) at four study sites during the period 1960 to 2002.

	Frequency of drought conditions (SPI<-1)		
Site	ond	jfm	ondjfm
Bulawayo	19	16	26
Gweru	19	12	21
Masvingo	19	21	17
Mt. Darwin	12	23	21

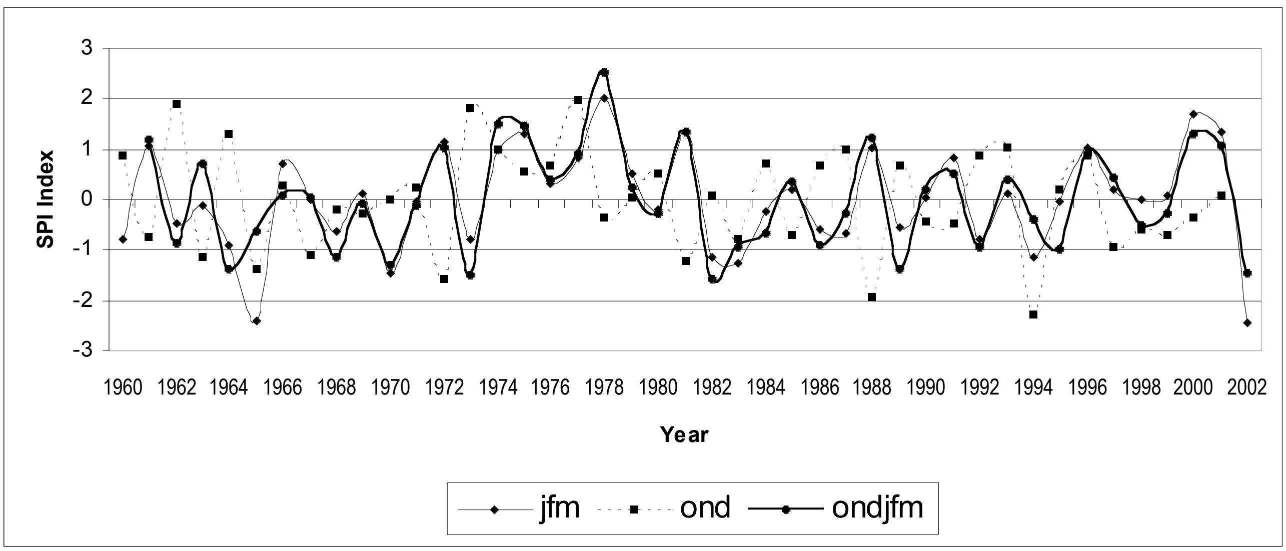


Figure 3. 4 Standardised Precipitation Index (SPI) for Bulawayo from 1960 – 2002

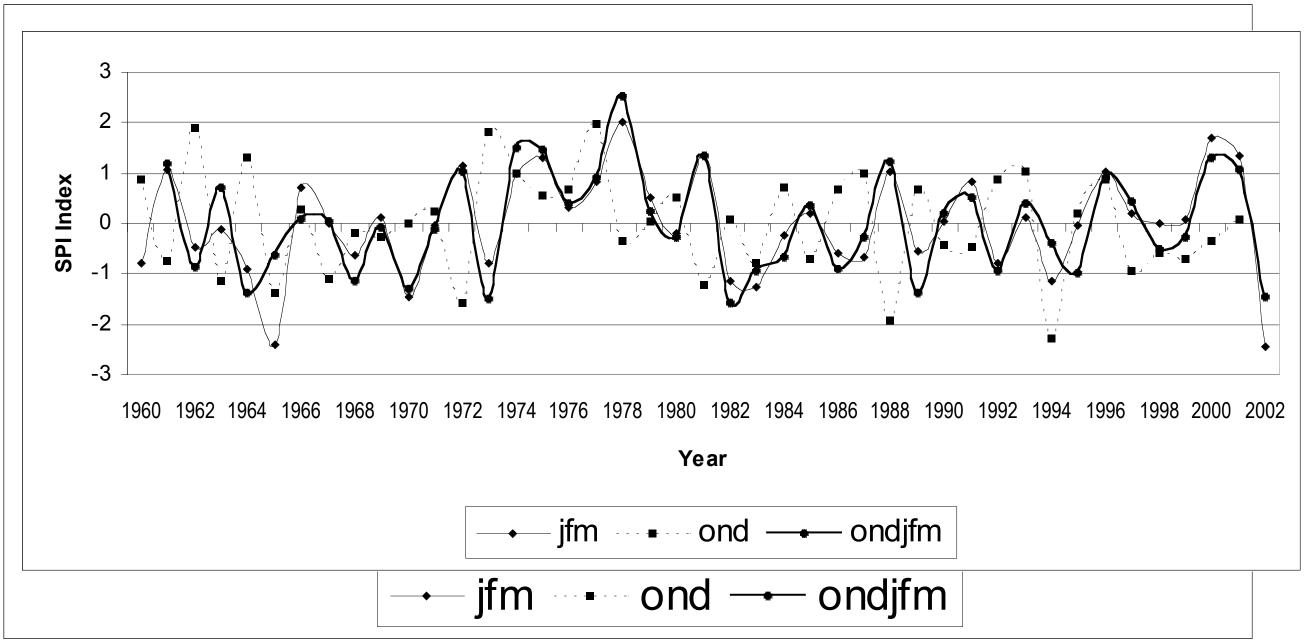


Figure 3. 5 Standardised Precipitation Index (SPI) for Gweru from 1960 – 2002

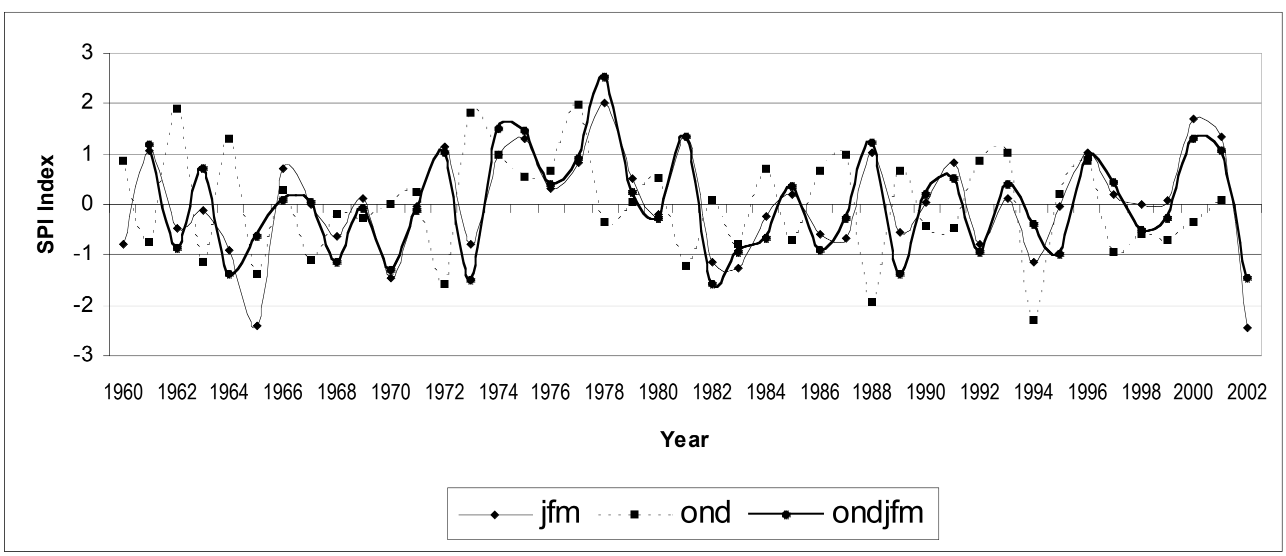


Figure 3. 6 Standardised Precipitation Index (SPI) for Masvingo from 1960 – 2002

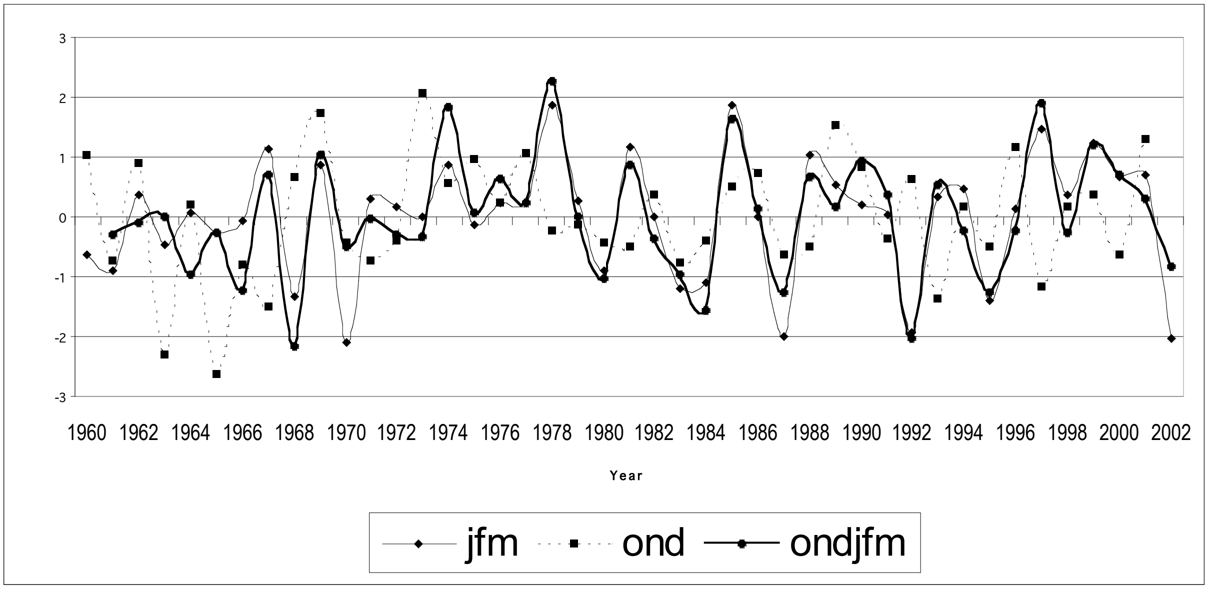


Figure 3.7 Standardised Precipitation Index (SPI) for Mt. Darwin from 1960 – 2002

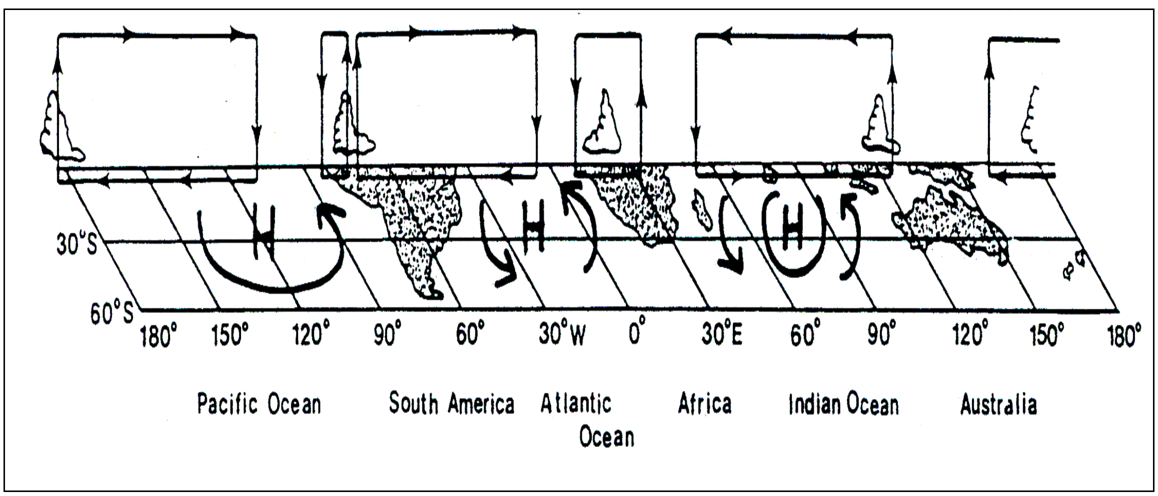


Figure 3.8 A schematic representation of the zonal Walker Circulation (Indeje, 2001).

The influence of ENSO on Zimbabwe summer rainfall is due to the fact that changes in the large-scale flow (Fig. 3.8) are associated with changes in the location of major centers of convection and partly to the consequent changes in the frequency and location of blocking and of the storm tracks (Burroughs, 1992; Frederiksen and Frederiksen, 1993). Displacements of cloud bands associated with tropical - mid-latitude troughs between two preferred locations one over mainland southern Africa and the other over Madagascar

(Fig. 3.9) occur between cold and warm ENSO events (Rocha and Simmonds, 1997a). This displacement has been associated with reversals in the direction of the zonal Walker Circulation over the Indian Ocean. The preferred trough location over or slightly east of Madagascar (Fig. 3.10) during warm ENSO years results in lower than normal rainfall over much of interior southern Africa (Tyson and Preston-Whyte, 2000).

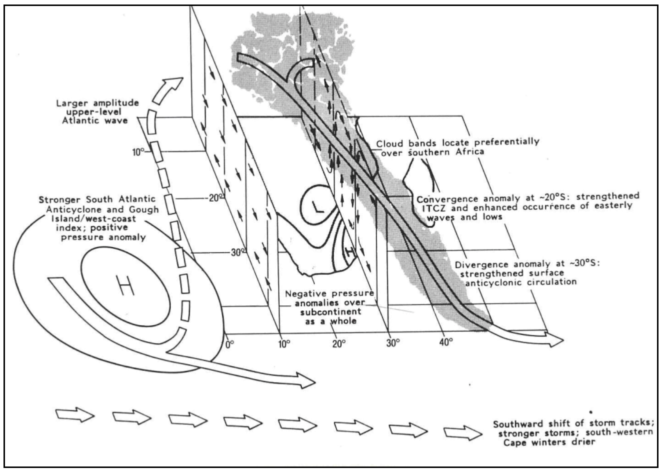


Figure 3. 9 Preferred trough location during cold ENSO episode years

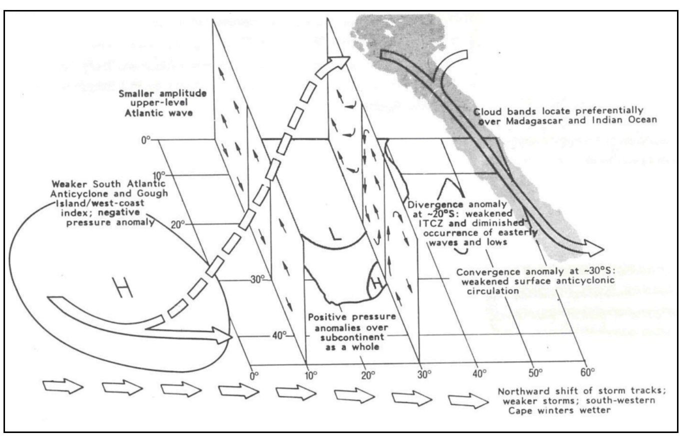


Figure 3. 10 Preferred trough location during warm ENSO episode years

Changes in the preferred location of cloud bands during ENSO phase shifts might therefore explain most of the observed statistical relationship between ENSO and inter-annual rainfall variability over Zimbabwe. Some studies suggest that the influence of the ENSO signal is not very strong in southern Africa and suggest that most of the observed inter-annual rainfall variability is largely a response to sea surface temperature anomalies in the Indian and southern Atlantic ocean that may not be linked to ENSO (Mason, 1995). Results in this study suggest that the influence of ENSO on Zimbabwe summer rainfall strongest during October to December and is greatly diminished from January onwards. It is possible that from January to March the sea surface anomaly pattern in the oceans surrounding southern Africa play a more significant role in modulating the rainfall pattern than events in the Pacific. It has been observed for example that tropical cyclones in the western Indian ocean, depending on their trajectory can greatly alter the character of the rainfall season in Zimbabwe mostly during January to March by either bringing about copious rainfall or extended dry spells.

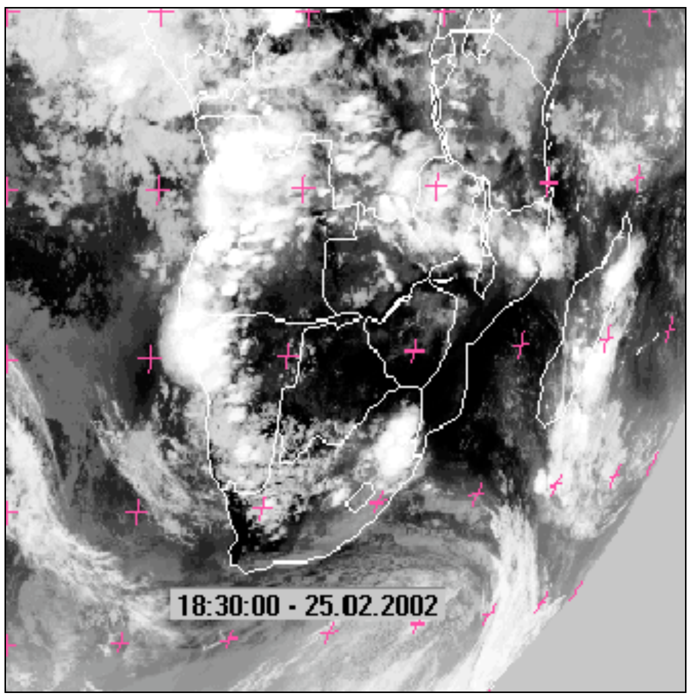


Figure 3. 11 Typical satellite image (25 February 2002) for an extended mid-season dry spell during the second part of the 2001-2002 rainfall season

3.5 SYNTHESIS

In concluding this chapter it can be confirmed that there is a statistically significant relationship between ENSO phase shifts and interannual summer rainfall fluctuations in

Zimbabwe. However, the strength of the relationship is not homogeneous across the country. The SOI during July, August and September correlates negatively with summer rainfall throughout the country although statistically significant correlations of up to –0.4 are found only in the central to southern sections of the country. Furthermore, the ENSO signal influences OND rainfall anomalies more than JFM. It is therefore possible that causes of the rainfall pattern observed during JFM could be found in the SST anomalies in the surrounding oceans.

The risk of October to March rainfall lying in the driest 20% of the years increases to about 21 to 40, 16 to 26, and 0 to 22% during warm, neutral and cold ENSO phases respectively depending on the site. Except in the northern sections of the country, the risk of a drought is greatest during the warm ENSO phase at most sites. The risk of drought during OND ranges from 21 to 42% compared with 9 to 38% during JFM across the study sites for the warm ENSO phase. During the neutral ENSO phase, the risk of drought ranges from 11 to 25%, compared with 16 to 30% during JFM across the eight stations. From 1916 to 2002, the frequency of occurrence of the three ENSO phases was 28% (warm), 51% (neutral) and 21% (cold). Empirical evidence shows that the impacts of drought on smallholder agriculture and other economic sectors in Zimbabwe can be devastating. From this risk analysis, it can be concluded that the likelihood of drought ranges from low to high as one moves from the north to the south of the country. The impact of drought would also tend to be lower in the northern than the southern sections of Zimbabwe.

Chapter 4

ECONOMIC VALUE OF USING ENSO PHASE INFORMATION FOR RISK MANAGEMENT AMONG SMALL-HOLDER CROPPING SYSTEMS IN ZIMBABWE

4.1 INTRODUCTION

The previous sections have quantified the climate risk farmers are exposed to and the nature of the rainfall-ENSO association at the study sites. This chapter focuses on risk management. The risks confronted by farmers are many. On a daily basis farmers are confronted with an ever-changing landscape of possible price, yield and other outcomes that affect their financial returns and overall welfare. The consequences of decisions or events are not known with certainty until long after the outcome of those decisions or events occur. So outcome may be better or worse than expected. In an ever changing environment, a more sophisticated understanding of risk and risk management is important to help farmers make better decisions in risky situations and to assist policy makers in assessing the effectiveness of different types of risk protection tools.

Climate variability pervades agricultural decision making in Zimbabwe. Recent advances in the understanding of the El Nino – Southern Oscillation (ENSO) phase shifts and their influence on inter-annual rainfall variability has provided a basis for improved crop management decision-making in those areas where the ENSO signature on inter-annual rainfall variability is statistically significant. Knowledge of likely future seasonal conditions can be used at farm scale to adjust crop mix, proportion of crops to be grown, fertilizer application rates, sowing windows and cultivar choice. In the previous chapter, the relationships between ENSO and rainfall at the study sites were presented. In this chapter, the feasibility and economic worth of using seasonal climate forecasts in smallholder cropping systems management is investigated using a case study approach. It is assumed that an effective application of climate information is that which leads to a change in a decision and results in either an economic improvement or a reduction in risk.

It is further assumed that, for farmers to adopt new technology in their decision-making, that technology has to:

- Be effective within farmer circumstances
- Increase food production
- Reduce risk
- Enhance soil fertility
- Blend with what the farmer already knows, and
- Bring about a positive net economic return

The research questions posed are:

i. Given a perfect knowledge of the ENSO state during July to September what farm management strategies give the best economic return to a smallholder farmer in the long-term?.
ii. What is the opportunity cost of a false alarm?

4.2 DATA AND METHODOLOGY

4.2.1 Agronomic data

The National Early Warning Unit (NEWU) for Food Security provided historical district level cereal crop yield data. The yield records spanned the period 1980 to 2000. The Zimbabwe Central Statistical Office compiles official crop yield data from sample surveys. Unlike cash crops, the authenticity of the historical yield data for grain crops in Zimbabwe is difficult to ascertain largely because smallholder farmers do not usually keep proper records and the methods used to determine district yield are generally not accurate. The yield potential for maize, peanuts and sorghum for Zimbabwe is presented in Table 4.1 under three environmental potential scenarios.

Table 4. 1 Yield potential of three of the crops used in the study under three environmental potential scenarios (Source: Seed co, 2001).

Crop	**Environmental Potential**		
	Low	**Medium**	**High**
Maize	3 t/ha	6 t/ha	10 t/ha
Peanuts (short season – unshelled)	1.0 t/ha	2.0 t/ha	3.0 t/ha
Peanuts (long season, unshelled)	2.0 t/ha	3.5 t/ha	5.0 t/ha
Sorghum (white)	0.5 t/ha	1.5 t/ha	3.0 t/ha
Sorghum (red)	2.0 t/ha	4.0 t/ha	6.0 t/ha

Maize (Zea mays, L) grows best on deep, well-drained, fertile soils and where total seasonal rainfall exceeds 500 mm. Maize is susceptible to both drought and water logging. Drought during the four week period spanning flowering (silking and tasseling) can lead to serious loss of yield. The later maize is planted, the lower the yield. November planting with the first rains is usually considered the safest under dry land conditions (Seedco, 2001). The UZ Soil Science Department recommends a Nitrogen fertilizer management strategy that involves split applications at 10 days after emergence, 30 and 60 days later depending on rainfall pattern. Table 4.2 summarizes the recommended fertilizer application rates for maize for different yield targets. Each 50 kg bag of Ammonium Nitrate contains 18 Kg of Nitrogen. The simulations in this study use 9 and 18 kgs of Nitrogen at planting or 35 days after planting which is equivalent to half and one bag of ammonium nitrate respectively.

Table 4. 2 Recommended fertilizer application rates for corresponding maize yield

Type of Fertilizer	Yield potential of maize			
	< 3 t/ha	3 to 5 t/ha	5 to 8 t/ha	> 8 t/ha
	Number of 50 kg bags of fertilizer per ha			
Compound D or Z	0 to 3	2 to 5	5 to 7	6 to 12
Ammonium Nitrate	1to 3	2 to 5	5 to 7	6 to 10

Sorghum grows best in warm areas and is drought tolerant. It is normally planted in early December. Peanuts do well in deep well-drained soils. Suitable soils include sand and sandy loams. It is recommended that peanuts be planted before the end of November. Cowpeas are an ideal dry land crop for low rainfall areas because of their drought resistance characteristic. They also provide excellent human nutrition and crop rotation benefits. They can be grown on their own or intercropped with maize.

4.2.2 Climatic data

Observed daily climatic data comprising maximum and minimum temperature, rainfall, sunshine or radiation was obtained from the Zimbabwe Department of Meteorological Services for the study sites. The data spanned the period 1951 to 2002 with variations from one station to the other. Sunshine data was used to fill gaps in radiation data using the formulated presented in chapter 2. Since crop simulation modeling does not allow gaps in meteorological files, data from nearby stations was used to patch up few gaps at some of the stations. Generally the stations used in the study had more than 98% of the records.

4.2.3 Economic data and gross margins

World prices for seed, fertilizer and farm gate producer prices were used to determine gross margins. The prices are kept constant during period of study so as to eliminate price related yearly fluctuations in gross margins. Historical prices for seed, fertilizer and producer prices for the crops used in the study were obtained from the relevant organizations in Zimbabwe. This data is used to assess changes in the farmer's operating environment through time.

Table 4. 3 World prices for agricultural commodities and inputs (Source: WB)

World prices for GM computations			
crop	output price(US$/tonne)	Seed price(US$/kg)	fertilizer(AN)(US$/tonne)
sorghum	265	5.3	70
g/nuts	875	0.86	70
cowpea	833.3	2.22	70
maize	190	0.84	70

The conceptual framework in Fig 4.1 is used to determine the economic value of ENSO phase information before planting. To determine the potential economic value of seasonal climate forecasts or use of ENSO phase shift information in smallholder farm management, an approach similar to that used by McCarl*, et al.*, (2000) is used. Two fundamentally different farmer decision-making frameworks are used.

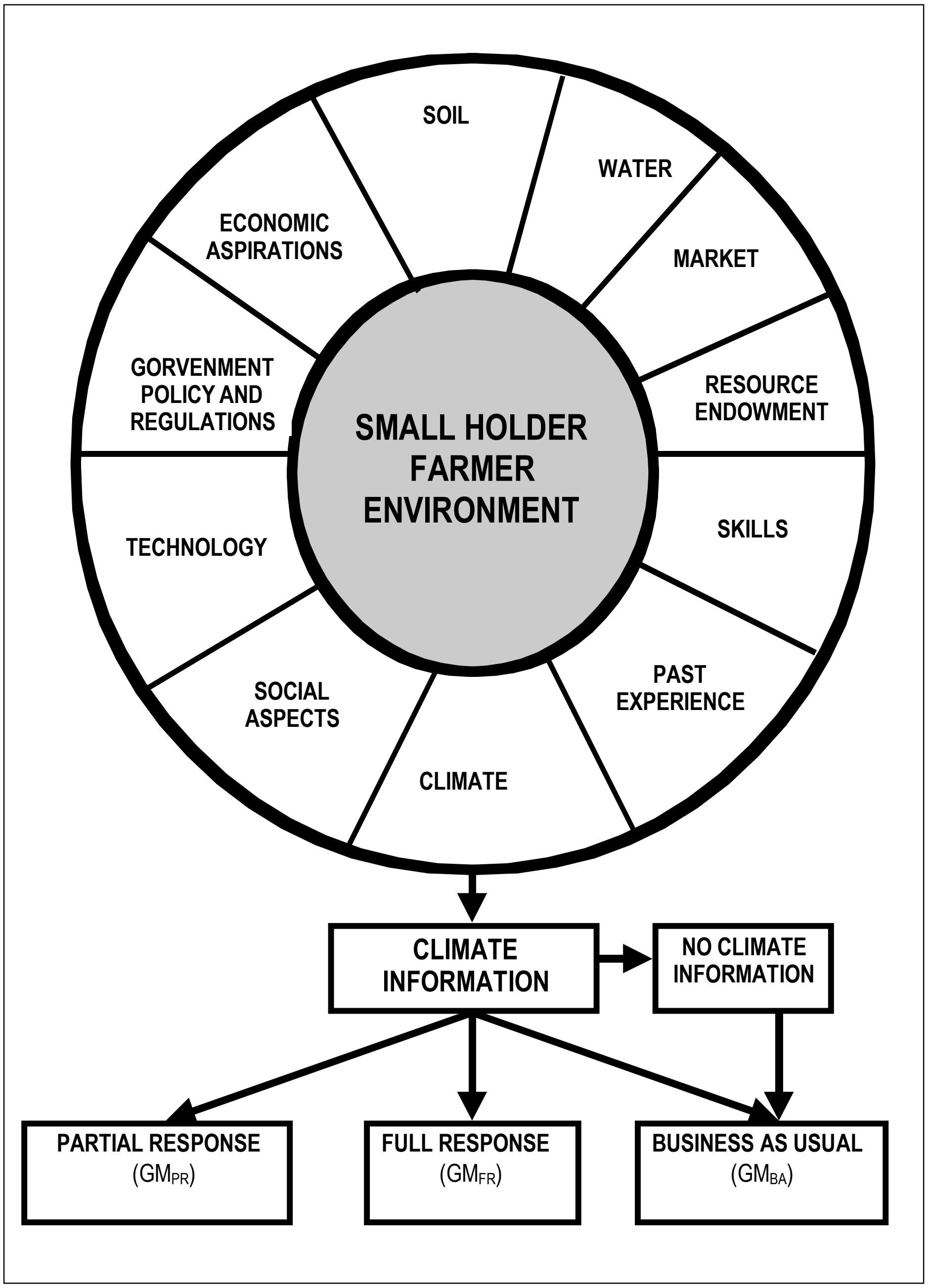


Figure 4. 1 Conceptual framework for the evaluation of the economic worth of ENSO phase information

In the first scenario, smallholder farmers are assumed to be operating without use of any seasonal climate forecast or ENSO phase information. This situation can arise from lack of access to the information or unwillingness to respond to the information. Under this scenario it is further assumed that a farmer would choose a crop plan that gives the best return over a long period of time. Such a plan represents a conservative risk management strategy and would give a gross margin (GM_{BA}). This scenario is referred to as "Business as Usual" or "Without ENSO information" scenario.

In the second scenario, smallholder farmers are assumed to incorporate ENSO phase shift information fully and thus select a crop plan that gives the highest Gross Margin (GM_{FR}) in that individual ENSO phase. Thus crop mix, nitrogen management, cultivar and sowing wind choices that give the highest GM are selected for each ENSO phase.

The Marginal Gross Margin (MGM_{FR}) associated with a full response to ENSO phase information is then given by:

$$MGM_{FR} = GM_{FR} – GM_{BA}$$

And for a partial response scenario the Marginal Gross Margin (MGM_{PR}) is given by:

$$MGM_{PR} = GM_{PR} – GM_{BA}$$

Where GM_{FR} is the Gross Margin for a full response, GM_{PR} is gross margin for partial response and GM_{BA} is gross margin for business as usual.

These computations are concerned with decisions made at planting only. Therefore fertilizer application beyond 35 days after planting, labor and chemical use are not included. Gross Margins are also influenced by crop price in relation to input costs. To eliminate fluctuations in gross margins emanating from crop price or input price fluctuations, producer prices were kept constant from one year to the other in quantifying gross margins.

4.2.4 Surveys

Baseline surveys involving 300 households (100 per each of the three survey areas, Buhera, Serima and Mhondoro) were contacted during three crop growing seasons (1999/2000), 2000/2001 and 2001/2002) to establish:

- current farmer practices that the project was seeking to influence,
- the farmer's decision making environment
- farmer's risk perception and management strategies.

Farmers were classified into three wealth categories (poor, average and rich) based on the community wealth ranking technique. Structured questionnaires were used in face-to-face interviews to capture information from the farmers and extension officers.

4.2.5 Crop modeling

Crop simulation modeling in conjunction with historical climate records from the selected study sites is used to assess economic and agronomic consequences of shifting crop management strategies in response to ENSO phase shifts during July to September each year. The Agricultural Production Systems Simulator (APSIM) is a simulation environment designed to simulate the production and resource consequences of agricultural systems (Meinke, et. al., 1998). The APSIM model was calibrated for use in Zimbabwe through experiments at Agricultural Research Stations in the country (Shamudzarira, *et al*. 2003, Dimes, personal communication). In this study, four crops, maize (*zea mays*), sorghum (sorghum bicolor L), groundnuts ( ) and cowpea ( ) are used. The SC401 and SC709 maize varieties are used in the simulations. The agronomic characteristics of the commonly used maize varieties in Zimbabwe are shown in Fig 4.2.

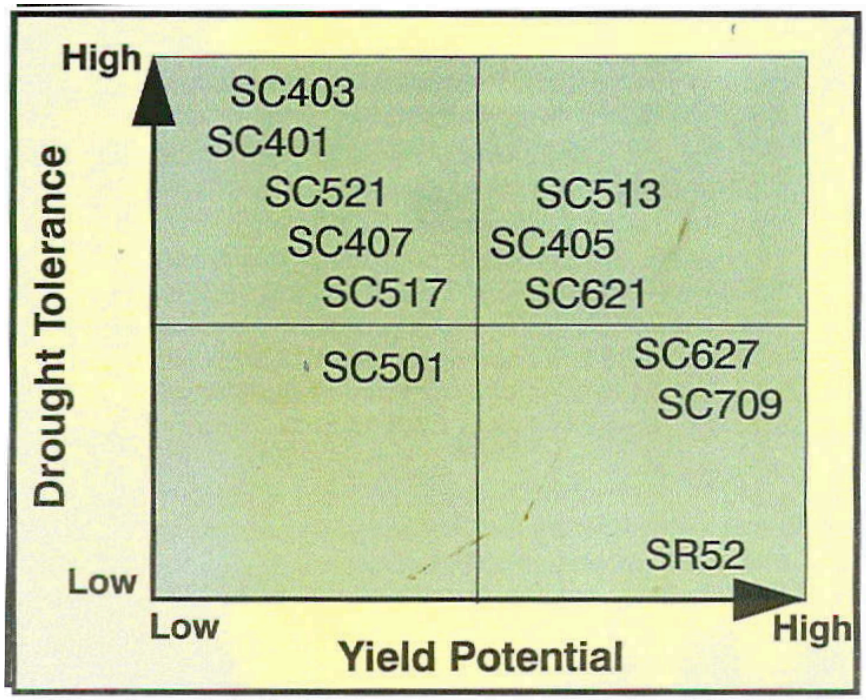


Figure 4. 2 Maize hybrid characteristics (Source: SEEDCO, 2001)

Surveys involving smallholder farmers in Serima and Mhondoro showed that most smallholder farmers in those areas use a fixed cropping strategy that revolves around maize largely because of their food self-sufficiency goal whether a poor or good season is predicted. This fixed strategy is contrasted with a variable strategy whereby four management options (growing maize, sorghum, groundnuts or cowpea) can be implemented during different sowing windows (SEEDCO 2001) for short, medium or long season varieties with three nitrogen application levels (0, 9 or 18 kg/ha). Typical sowing windows vary with site (Annex 2) and these were ascertained from literature and interviews with agricultural experts from the Agricultural Research and Extension Services (AREX).

4.3 RESULTS AND DISCUSSION

4.3.1 Characterization of Zimbabwe small-holder farmers

Smallholder farmers in the three survey areas generally have up to two (2) hectares of land under rain fed crops. Wherever possible each household has smaller pieces of the two hectares under different soil types to include a vlei. Vlei soils have good water retention characteristics and planting on these soils is as early as August in most places to enable the sensitive crop development phases to escape possible water logging later on in the season. Crop plans are largely determined by household food preference and tradition. The predominant crop grown is the short season maize variety (Table 4.4). Maize is largely grown for food with the surplus being sold for cash income. A major characteristic of Zimbabwe's smallholder farmers is their dependence on hybrid seed until recently. Crops such as paprika are grown mainly for cash (Fig 4.3) but the land under this crop is negligible.

Table 4. 4 Percentage plots allocation by crop.

Crop	% of Total Plots allocated			% of Total Acreage allocated		
	Ward 5	Ward 6	Both	Ward 5	Ward 6	Both
Maize	62.7	60.0	61.2	75.8	73.8	74.8
Groundnuts	27.2	11.0	18.1	17.6	7.4	12.6
Rappoko	6.1	16.2	11.8	4.4	10.4	7.4
Rice	2.6	5.5	4.2	1.8	3.3	2.6
Groundnuts	0.9	2.8	1.9	0.3	1.2	0.7
Cowpeas	0.0	1.7	1.0	0.0	1.3	0.6
Beans	0.4	1.0	0.8	0.3	0.9	0.6
Parprika	0.0	1.4	0.8	0.0	0.6	0.3
Potatoes	0.0	0.7	0.4	0.0	0.6	0.3
Sunflower	0.4	0.0	0.2	0.0	0.3	0.1
Millet	0.0	0.3	0.2	0.0	0.1	0.1

About 70% of the households surveyed own cattle. Cattle provide draught power and are a traditional symbol of wealth. Up to 50% of the households own a functional radio. More than 90% of those interviewed during the survey indicated that they regularly get weather and climate information through the radio. However, 66% of the respondents rate the credibility of the forecasts as fair, and 28% say the forecasts are not reliable. Because of the perceived low and erratic rainfall trend, most farmers have adopted long-term drought mitigation strategies such as planting drought tolerant and early maturing maize cultivars and adjusted planting dates. 80% of the arable land is on sandy loams. Because of the high cost of finance, the cropping program is largely financed from farmers' own savings and repatriations from those in formal employment.

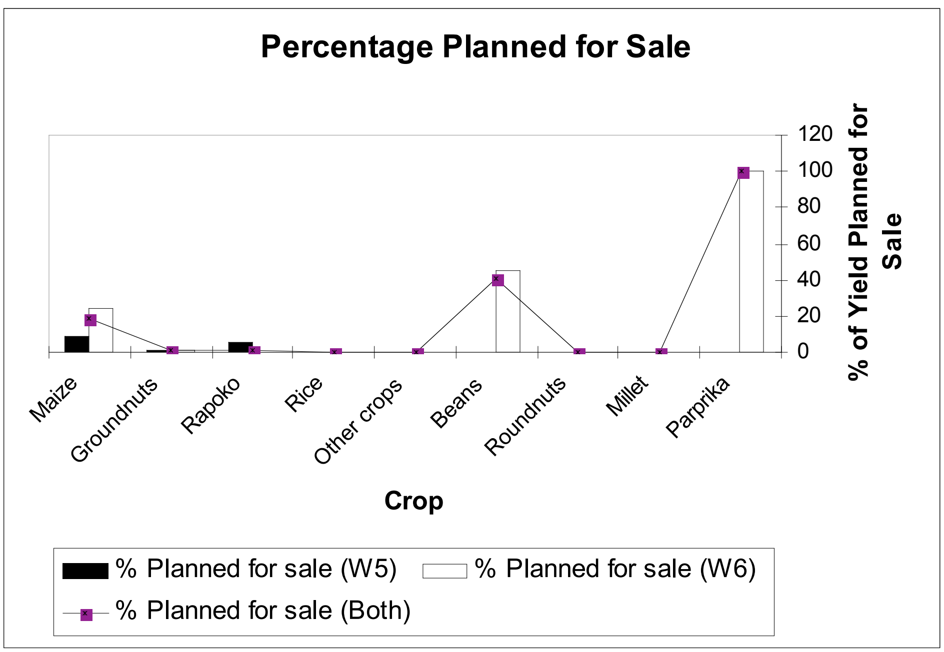


Figure 4. 3 Sale pattern of crops among smallholder farmers in Serima and Mhondoro communal lands

4.4 RISKS OF CONCERN TO FARMERS

Understanding the risks farmers are exposed to is the first step towards formulating a meaningful framework for the application of seasonal climate forecasts. From the interviews carried out with small-holder farmers in Serima, Buhera and Mhondoro communal lands, two risk categories, namely production and market risks, emerged as the most important for the farmers. The market risk is closely related to a third risk category, institutional risk. The sections that follow elaborate on these risks.

4.4.1 Production risk (decrease in crop yields)

Crop yield risk varies regionally in response to soil type, climate and the use of irrigation.

Table 4. 5 Sensitivity analysis of average observed maize and sorghum yield in two natural regions for three rainfall scenarios from 1980 to 1996

Crop	Rainfall	Natural Region III		Natural Region IV	
		Ave. Yield (kg/ha)	% change from average	Ave. yield (Kg/ha)	% change from average
Maize	Wet	1303	-8	712	8
	Below Normal	743	-47	200	-70
	Normal	1414	-	657	-
Sorghum	Wet	614	-17	709	70
	Below Normal	685	-7	280	-33
	Normal	740	-	418	-

In Natural region III and IV maize yield can be reduced by up to 47 and 70% respectively during poor rainfall years. For the same rainfall scenario (below normal) sorghum yield reduces by 7 and 33% in the two regions respectively.

4.4.2 Market risk

Uncertainty in commodity prices is a big challenge for farmers. Yields and prices tend to move in opposite directions for agricultural commodities. However, price controls may distort this relationship. Since the mid-1990s, high levels of inflation have characterized Zimbabwe's macroeconomic environment and this is reflected in the local price movements of agricultural commodities and inputs (Fig 4.4). Whereas the producer prices of peanuts and sorghum have grown tremendously between 1990 and 2000, the same cannot be said of maize, which is, controlled commodity (Fig 4.4). The absence of market forces in the determination of the producer price for maize, a commodity grown by the majority of smallholder farmers greatly exposes the farmers to institutional risk. During drought years when the producer price of maize could firm, this is kept in check through policy instruments and the law compelling all producers to sell their maize through the country Grain Marketing Board.

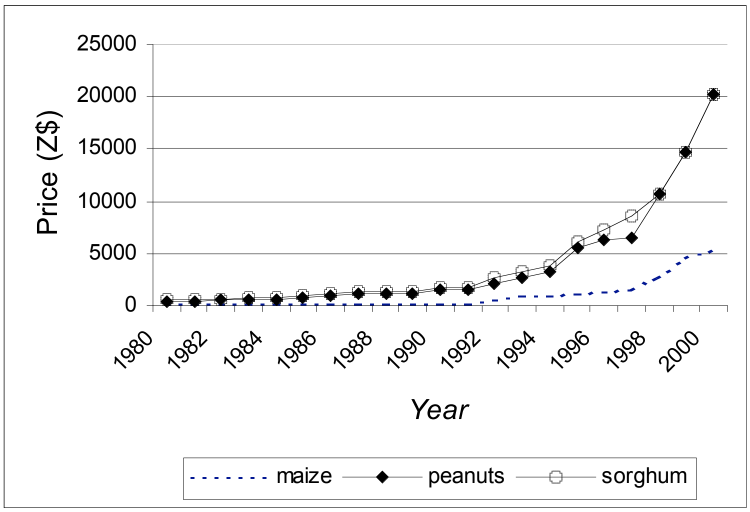


Figure 4. 4 Producer price of maize, peanuts and sorghum from 1980 to 2000.

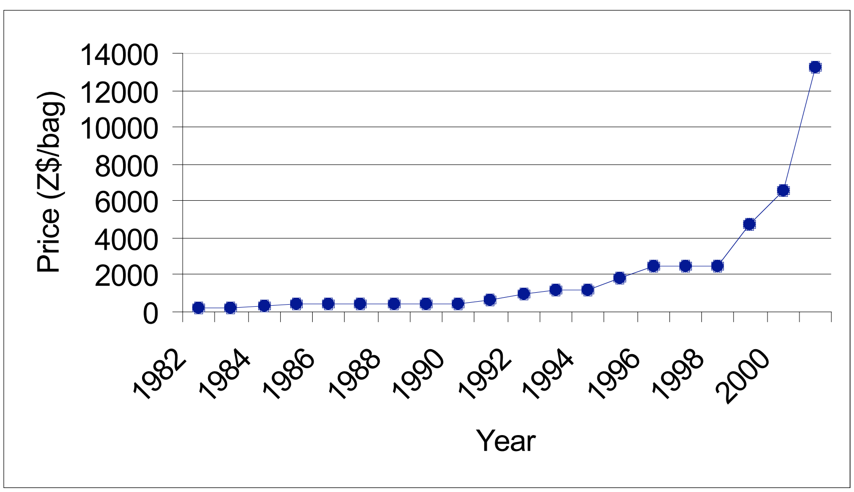


Figure 4. 5 Price of Ammonium Nitrate Fertilizer

The spiraling cost of inputs (fig 4.5 and 4.6) Vis a Vis the controlled maize producer prices has adversely affected the ability of smallholder farmers to use optimum crop management strategies particularly after the year 2000.

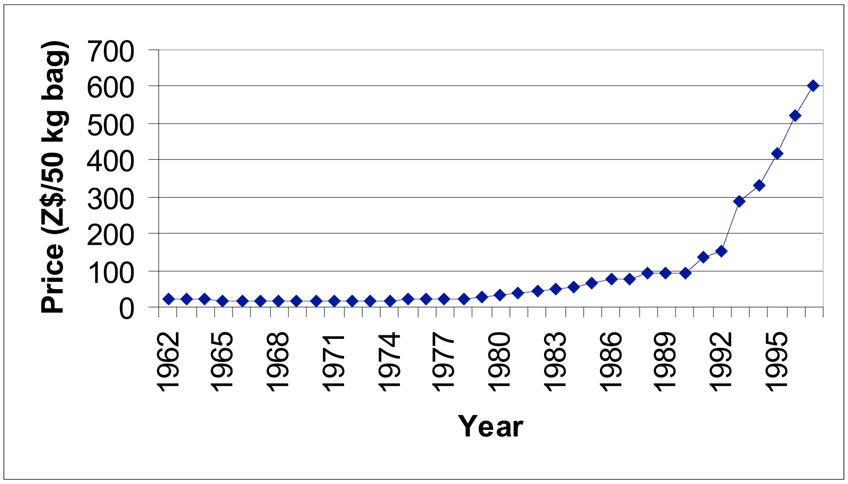


Figure 4. 6 Prices of hybrid maize seed

4.4.3 Institutional risk (changes in government laws, policies and regulations)

Price controls and marketing channels have been the main policy instruments used by the Zimbabwe government to ensure that food is available to urban consumers at an affordable price. The price controls on inputs have often created severe shortages on the market leading to depressed national crop production and the evolution of thriving informal market. Seed sales from one of main local seed companies show the adverse impact of price controls on seed sales from 2000 to 2002. In 1997, seed sales also dropped (Fig 4.7) as farmers responded to the El Nino news by cutting back on land under maize.

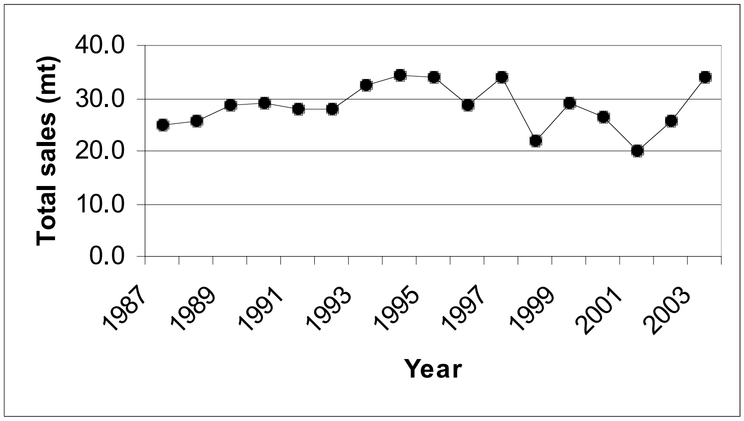


Figure 4. 7 Seed sales by one Zimbabwe Company from 1987 to 2003.

4.4.4 Simulation of crop yields

The APSIM model simulates crop yields in Natural Region III, IV and V quite well (Fig. 4.8 – 4.10). The model underwent extensive calibration at an agricultural research station in the Masvingo province. Its simulation of crop yields under agricultural research site conditions is excellent (Shamudzarira, personal communication). Using communal area crop yields, the correlation between observed and simulated maize yields is 0.6 for Masvingo, and much less at the other sites. In the northern sections of the country the model crop yield simulations are poor. From this analyses it can be concluded that simulation results in the southern sections of the country can be used with confidence to assess the economic value of ENSO phase information.

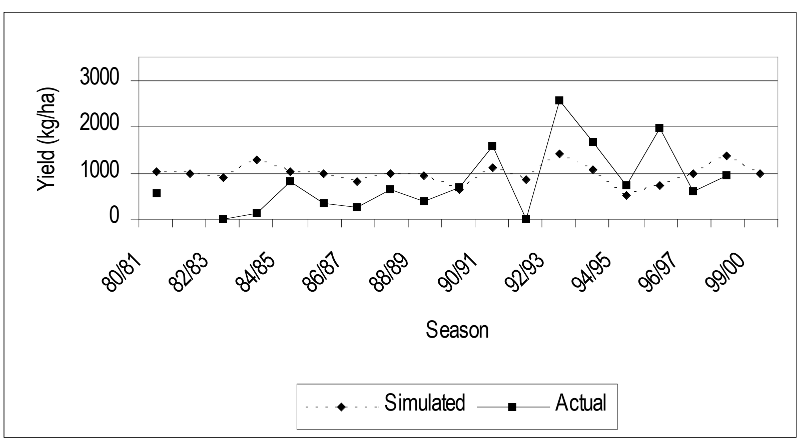


Figure 4. 8 Simulated and observed maize yield at Masvingo.

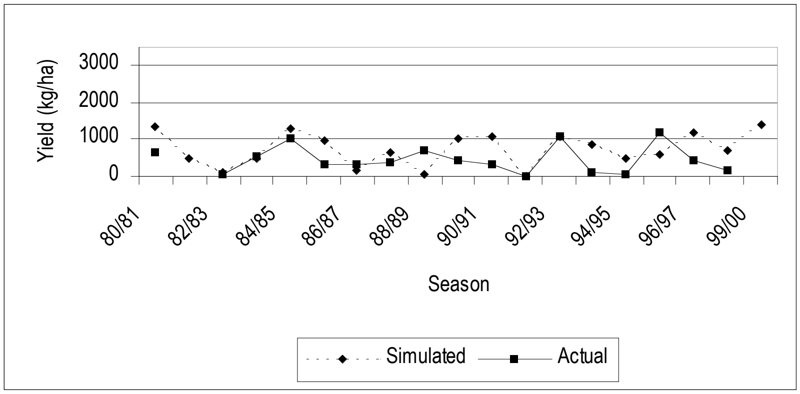


Figure 4. 9 Simulated and observed maize yield at Chiredzi

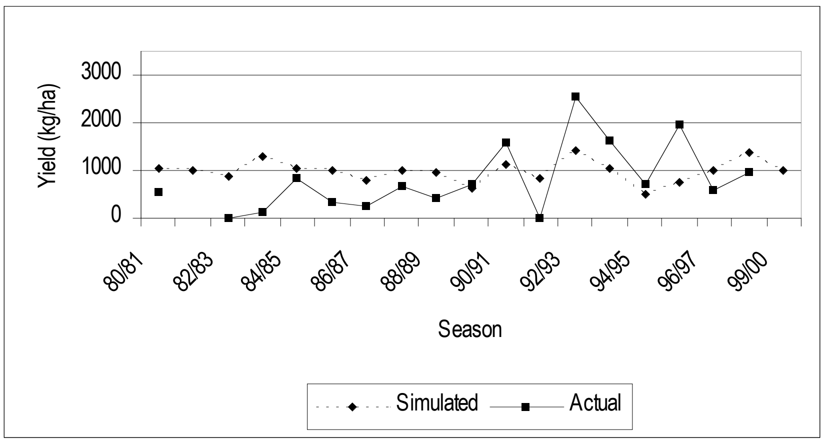
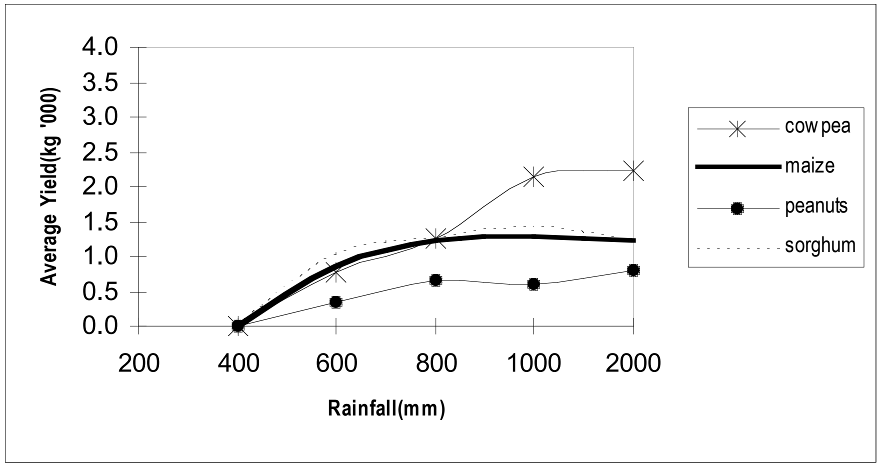


Figure 4. 10 Simulated and observed maize yield at Gweru

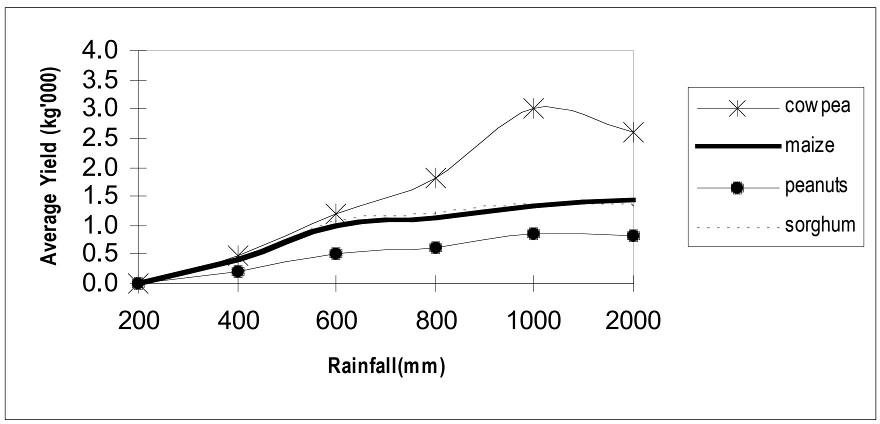
Crop yields increase almost linearly with rainfall up to a certain point at all the simulation sites (Fig. 4.11 –4.14). At all the four sites presented (Fig. 4.11 –4.14) maize yields do not increase much beyond 600 mm of total seasonal (October to March) rainfall. However, for cowpeas the threshold beyond which yields start to decline is 800 to 1000 mm depending on the site.

Of the four crops simulated cowpeas produce the highest yield at all the study sites across the three ENSO states. Peanuts produce the lowest yield in all cases. During El Nino events, sorghum yields tend to be marginally higher than other crops especially at Bulawayo and Mt. Darwin. From this analysis it can be concluded that since smallholder farmers have a high preference for maize production they may be missing on opportunities for cash income available with other crops. A crop mix that involves cowpea presents itself as an optimum risk management strategy. Sorghum also appears to be a worthy option at all the sites across the three ENSO states.

ElNino



Neutral



LaNina

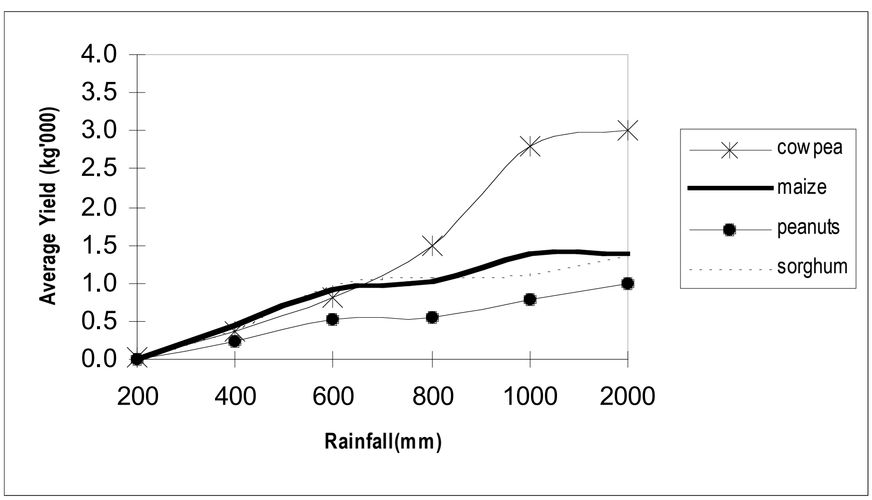
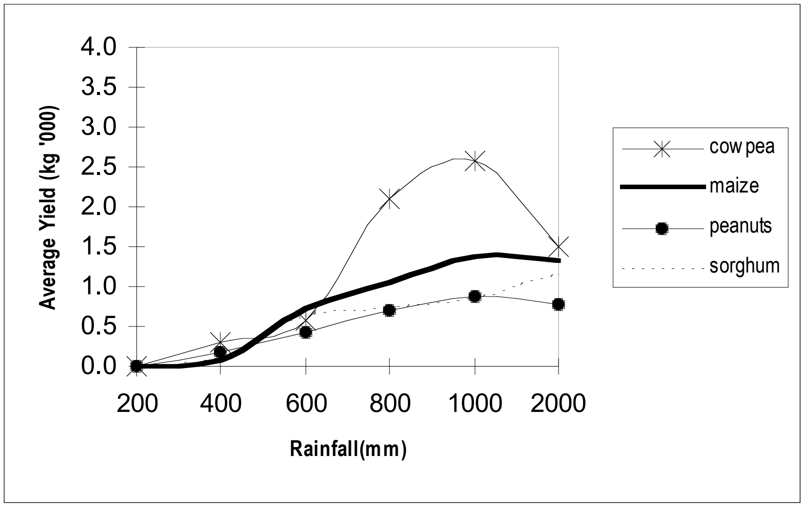
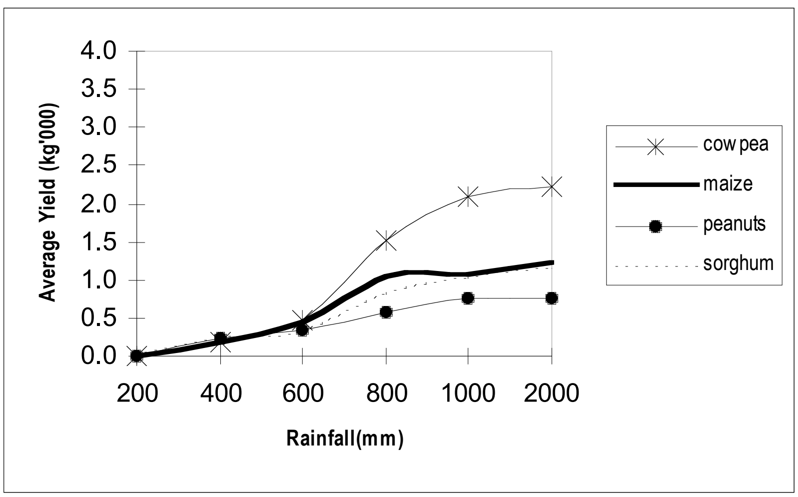


Figure 4. 1 Rainfall crop yield relation at Bulawayo during (a) El Nino, (b) neutral , c) La Nina phase.

ElNino



Neutral



LaNina

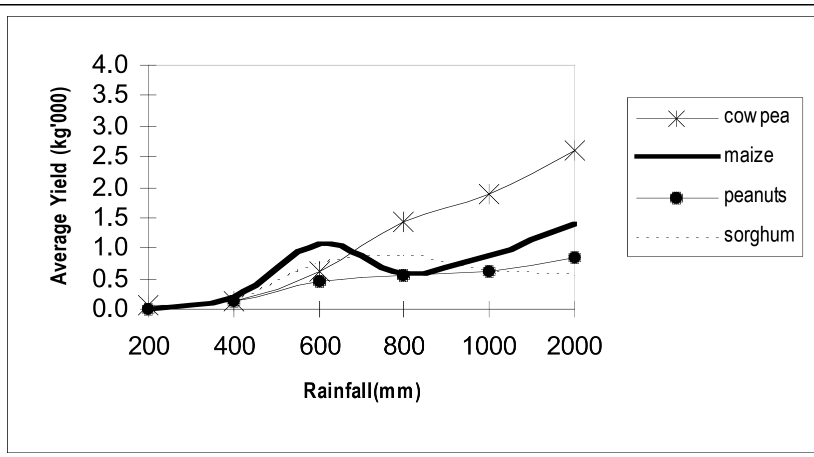
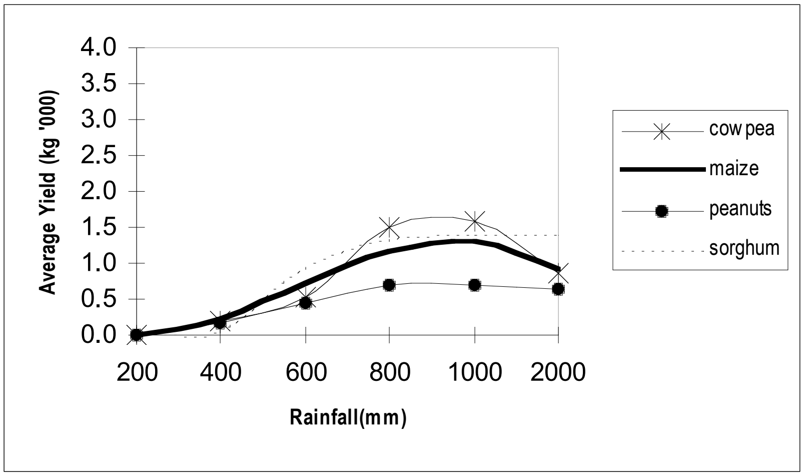
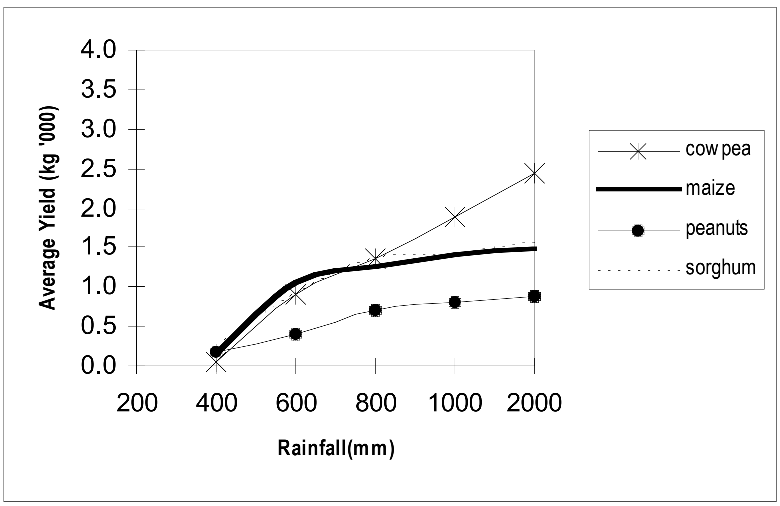


Figure 4. 2 Rainfall crop yield relation at Gweru during (a) El Nino, (b) neutral , c) La Nina phase

ElNino



Neutral



LaNina

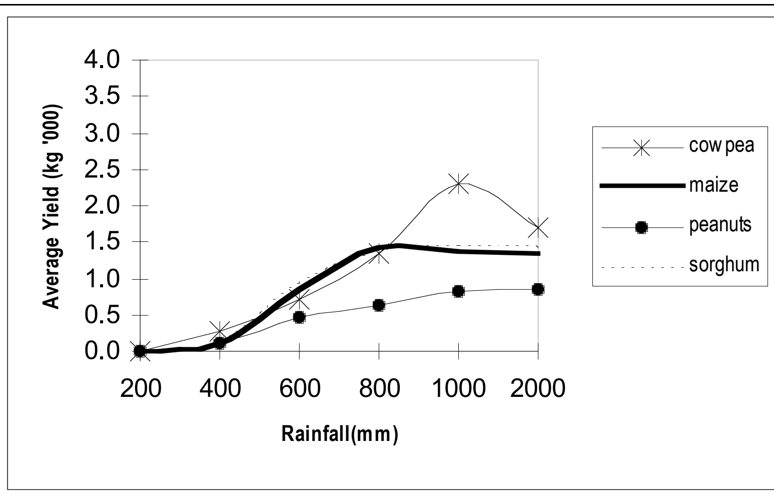


Figure 4. 3 Rainfall crop yield relation at Masvingo during (a) El Nino, (b) neutral , c) La Nina phase

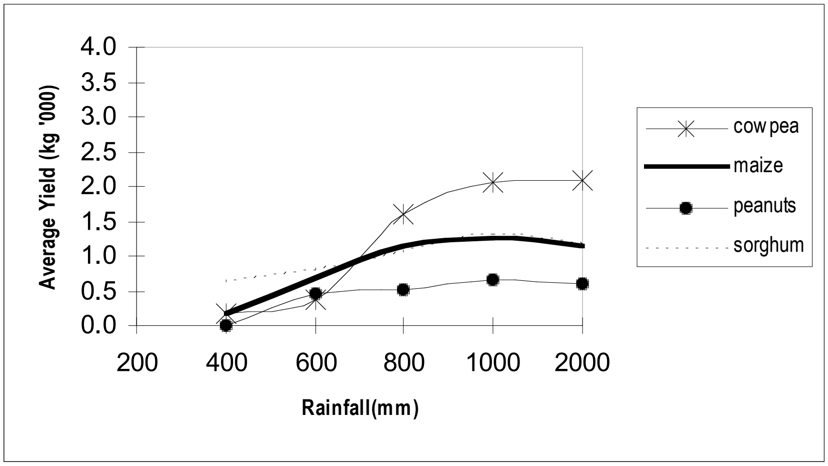
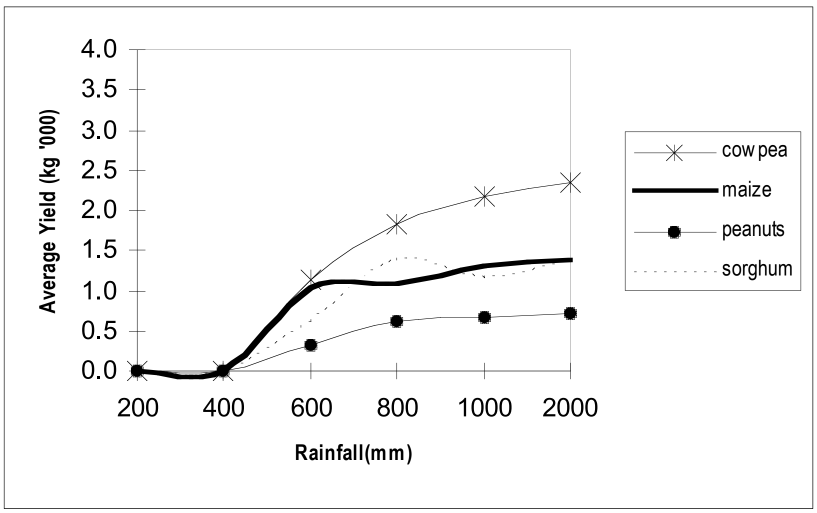
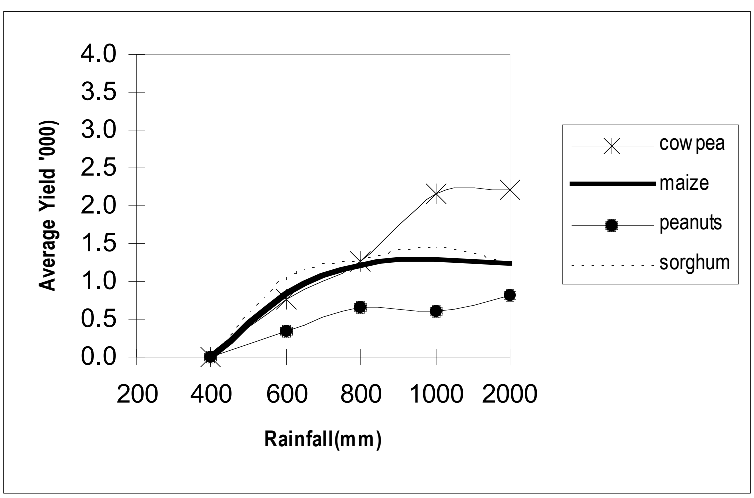
ElNino	
Neutral	
LaNina	

Figure 4. 4 Rainfall crop yield relation at Mt. Darwin during (a) El Nino, (b) neutral , c) La Nina phase

4.4.5 Economic value of ENSO forecasts to small-holder farmers

Adjusting crop management strategies during the neutral ENSO phase yields net positive economic returns for the smallholder farmer in the long run. The difference in gross margins between a full response to ENSO information and business as usual is summarized in Table 4… The full response strategy assumes the farmer chooses the optimum planting window for each crop and uses 18 kg of Nitrogen fertilizer at sowing or 18 days after sowing for maize. In addition the farmer could alter the crop mix. For a maize crop, a full response to El Nino information yields a marginal gross margin of 10 and 20 USD per hectare at Mt. Darwin and Harare respectively. A full response to El Nino generally yields negative returns for the smallholder farmer across most of the study sites except at Mt Darwin where maize and cowpea show positive marginal gross margins.

Adjusting maize management strategies during the neutral ENSO phase yields marginal gross margins ranging from 10 to 70 USD per hectare across the study sites. For cowpea, marginal gross margins range from 10 to 660 USD per hectare across the study sites, with the long season cultivar outperforming the short season during the neutral ENSO phase. The greatest returns are at Masvingo, Harare and Gweru. Adjusting sorghum and peanuts management strategies also yield positive economic returns during the neutral ENSO phase (Table 4.6)

In the previous chapter it was revealed that the risk of Zimbabwe summer rainfall falling in the lowest 20% of the years ranges from 21 to 40, 16 to 26 and 0 to 22% during the warm, neutral and cold ENSO phases respectively depending on location. It was further shown that the frequency of occurrence of the three ENSO phases is 28, 51 and 21% for the warm, neutral and cold phase respectively. The finding in this study that small-holder farmers will reap positive economic returns by using optimum management strategies during the neutral ENSO phase more than in the other two phases appears to be in harmony with the high frequency of occurrence of that phase.

Table 4.7 helps to understand risk management. Farmers manage agricultural risks in a number of ways such as adjusting the enterprise mix (diversification) or the financial structure of the farm enterprise. The risk of El Nino occurrence is relatively low (28%) and impacts significant compared with that for the neutral phase (51%).

Table 4. 6 Gross Margin for the crops with ENSO information management strategies

		maize		cowpea		sorghum		peanuts	
		long	short	long	short	Long	short	long	short
Bulawayo	ElNino	-0.01	-0.01	-0.04	-0.05	0.00	0.02	0.01	0.01
	LaNina	-0.02	-0.02	-0.09	-0.16	-0.06	-0.04	-0.04	-0.05
	Neutral	0.03	0.03	0.33	0.23	0.04	0.02	0.01	0.02
Chiredzi	ElNino	-0.02	-0.01	0.21	-0.07	0.01	-0.03	-0.04	-0.06
	LaNina	0.00	-0.01	-0.13	-0.01	0.04	0.03	-0.04	0.04
	Neutral	0.07	0.05	0.32	0.17	0.14	0.08	0.16	0.18
Gweru	ElNino	-0.01	0.00	-0.21	-0.12	0.00	0.00	0.02	0.05
	LaNina	-0.01	0.00	-0.28	-0.17	0.01	0.00	-0.01	-0.04
	Neutral	0.02	0.01	0.47	0.28	0.06	0.00	0.02	-0.01
Harare	ElNino	0.02	0.00	-0.24	0.00	-0.05	0.00	-0.02	-0.01
	LaNina	0.00	0.00	-0.31	-0.37	0.07	0.01	0.02	-0.03
	Neutral	0.02	0.01	0.66	0.48	0.08	0.03	0.02	0.05
Masvingo	ElNino	-0.03	-0.02	-0.30	-0.16	-0.02	-0.02	-0.05	-0.07
	LaNina	0.00	-0.01	0.01	-0.02	0.00	0.02	0.00	0.03
	Neutral	0.05	0.05	0.46	0.22	0.10	0.08	0.09	0.08
MT_Darwin	ElNino	0.01	0.01	0.10	0.06	0.01	-0.01	0.01	-0.02
	LaNina	-0.01	-0.01	-0.31	-0.18	0.01	0.00	0.00	-0.02
	Neutral	0.00	0.03	0.16	0.10	0.02	0.01	-0.01	0.08

To manage the impacts of an El Nino related drought considerable management effort, such as irrigation is required. This is beyond the means of most smallholder farmers and not economical considering the low market value of maize. Crop management strategies such as shifting..

Table 4. 7 Risk Management Model

IMPACT	**Risk Management Actions**		
Significant	Considerable management required	Must manage and monitor risks	Extensive management essential
Moderate	Risks may be worth accepting with monitoring	Management effort worthwhile	Management effort required
Minor	Accept risks	Accept, but monitor risks	Manage and monitor risks
	Low	Medium	High
		Likelihood	

Crop management strategies such as shifting planting windows, crop cultivar and nitrogen management are unlikely to be adequate during a severe El Nino induced drought. During neutral ENSO phase years, although the risk of drought also increases the impacts of rainfall variability are usually minor to moderate and for that reason the risks are manageable.

4.5 SYNTHESIS

The economic value of ENSO based seasonal climate forecasts in farm management depends on the ENSO phase. In concluding this chapter, it may be said that using optimum crop management strategies during the neutral ENSO phase yields the greatest economic returns for smallholder farmers in Zimbabwe.

An optimum crop mix could include cowpea and sorghum in addition to maize. Planting maize with 18 kilograms (one bag) of nitrogen or applying thirty-five days after sowing gives good returns under each of the three ENSO phases. A range of sowing windows could be used to optimize returns on each of the crops depending on the ENSO phase and site. On vile soils planting during the last week of August gives optimum returns in the Serima, Buhera and Mhondoro communal lands providing there is sufficient residual moisture.

The value of seasonal climate forecasts depends on site. For areas where the ENSO signal strongly influences inter-annual rainfall fluctuations such as the central and southern sections of Zimbabwe adjusting crop management strategies in response to ENSO phase shifts during July-September can yield net positive returns to the farmer over the long term. However, as one moves to the north of country, the value of seasonal climate forecasts diminishes. Disaster management programs reduce forecast value. Most smallholder farmers prefer business as usual since emergency relief programs come to their rescue during times of need.

Crop producer price in relation to production costs is an important factor in determining the farmer's economic well being given a highly variable rainfall regime. The prices of agricultural commodities usually move in opposite directions with volume of production. Government policies and regulation may however distort that relationship and ultimately the value of seasonal forecasts. Often high-risk decisions have high returns. The risk tolerance level of the farmer will determine the level of adjustment in crop management strategies for given ENSO information. A risk averse farmer would value seasonal climate forecasts less than a risk taker.

It must also be said that what works well at one site might not work well at another because of subtle differences in rainfall and soil characteristics as well as farmer skill and resource endowment. To determine the value of seasonal climate forecasts, several experiments are required at different locations. Because of the significant impacts of the El Nino phase, a lot more resources will be required to minimize the risk of loss in crop production during that phase than any other phase. For resource poor smallholder farmers management of El Nino phase is unlikely to be profitable for them in the long-term for as long as they have to grow maize for their livelihood.

Chapter 5

SUMMARY OF FINDINGS AND CONCLUSIONS

5.1 INTRODUCTION

Throughout its history, Zimbabwe has suffered from periodic droughts and floods. Crops have failed, livestock have perished in the thousands, water supplies have declined and massive food aid has been rendered to the population to avert starvation. Recent advances in the understanding of ENSO and its impacts on inter-annual rainfall variability around the globe have raised expectations of better crop production risk management in sub-Saharan Africa. In Zimbabwe, as is the case elsewhere, ENSO phase shifts can have strong local effects on crop production with some provinces more affected than others. A useful way to understand the effects of ENSO on crop yields is to simulate crop production under different climate and crop management scenarios. It is not feasible to run field experiments at hundreds of locations each year to test the effect of ENSO phase shifts. Over the last several years farmers have continued to shift towards improved crop varieties given their resource and environmental constraints. Crop management has also steadily improved over the years thereby reducing the adverse impact of El Nino events for example.

The sections that follow summarize the main findings from this study.

5.2 SUMMARY

A. *The El Nino – Southern Oscillation phenomenon and Zimbabwe summer rainfall*

i. ENSO phase during July to September explains up to 16% of the variance in Zimbabwe summer rainfall. The rainfall response to ENSO is greatest in the central and southern sections of the country. The rainfall response to ENSO is greater during October to December than January to March.

ii. The neutral ENSO phase has the highest frequency of occurrence (51%) compared with the El Nino (28%) and La Nina (21%) phases. Low rainfall has occurred during both the El Nino and neutral phases.

iii. Of the ten driest years in Zimbabwe during the period 1900 to 2002, 60% of the cases can be ascribed to El Nino.

iv. Three types of drought affect Zimbabwe. Type I drought is characterized by a dry OND and a wet JFM, type II has a wet OND and dry JFM, whereas type III is generally dry from November through March. Smallholder farmers tend to cope better with type I droughts than the other two.

B. *Economic value of using ENSO phase information for risk management among small-holder cropping systems in Zimbabwe*

i. Adjusting cropping plans in response to ENSO phase shifts has potential long-term economic benefits for smallholder farmers in Zimbabwe. The greatest economic returns are associated with the neutral ENSO phase. The greatest positive economic benefits are for farmers in the central and southern sections of Zimbabwe where the rainfall response to ENSO phase shifts is greatest. Farmers in the northern sections of the country are unlikely to benefit much from adjusting crop management strategies in response to ENSO information because of the little influence of ENSO on rainfall in those areas. This geographical variation allows for national level management of ENSO phase shifts.

ii. Cowpea performs better than most crops during the three ENSO phases studied. Therefore a crop mix that includes cowpea is recommended as a production and market risk management strategy for Zimbabwe smallholder farmers. Selection of optimum planting windows and cultivars are also critical risk management strategies.

iii. There are micro-level differences in soil and climate type from one geographical region to another. Farmer skills and resource endowment also differ. Therefore a risk management strategy that might work for a farmer in one geographical location is not guaranteed to succeed elsewhere. Region specific response strategies to ENSO phase shifts must therefore be formulated to ensure maximum returns for farmers.

iv. Risk management is a complex activity and requires reliable information. El Nino induced droughts occur on 21 to 40% of the occasions depending on location. When drought occurs the impacts are significant. Significant management effort, beyond cultivar, planting date and crop selection is required to reduce the risk of production loss during a severe drought. Given the fact that most smallholder farmers are resource poor, they are unlikely to be able to manage a severe ENSO induced drought. A response at macro-level (national or provincial) may be necessary for the nation to realize the economic benefits of appropriate response to seasonal climate forecasts.

5.3 SYNTHESIS

Having demonstrated that there is potential for smallholder farmers to improve their socio-economic welfare through appropriate response to climate information one is encouraged to take this project a step further. In the next phase, the main objective is to establish a working partnership with smallholder farmers to reduce crop production risk associated with ENSO related climate fluctuation and improve the farmers' economic wellbeing. The areas of intervention will include diversification of the farmer's enterprise to include drought proofing assets, selection of optimum planting windows, adjustment of crop mix and ensuring that there is an appropriate marketing strategy for the farmer's produce.

The approach and tools that will be used include:

- Site selection and characterization
- Develop whole farm nutrient management scenarios
- On farm experiment with three households in each of the three study areas (Buhera, Serima and Mhondoro)
- Study area climate characterization with farmers
- Develop with farmers resource allocation and cropping plan maps
- Develop and implement record keeping tools for the farmers
- Decision trees and rules of thumb
- Obtain farmer feedback

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ANNEX

Annex 1   El Nino – Southern Oscillation Classification (Source: NOAA/NCEP)

	JFM	AMJ	JAS	OND
1950	C	C	C	C
1951	C	N	N	W-
1952	N	N	N	N
1953	N	W-	W-	N
1954	N	N	C-	C
1955	C	C-	C-	C+
1956	C	C	C	C-
1957	N	W-	W	W
1958	W+	W	W-	W-
1959	W-	N	N	N
1960	N	N	N	N
1961	N	N	N	N
1962	N	N	N	N
1963	N	N	W-	W
1964	N	N	C-	C
1965	C-	N	W	W+
1966	W	W-	W-	N
1967	N	N	N	N
1968	N	N	N	W-
1969	W	W-	W-	W-
1970	W-	N	N	C
1971	C	C-	C-	C-
1972	N	W-	W	W+
1973	W	N	C-	C+
1974	C+	C	C-	C-
1975	C-	C-	C	C+
1976	C	N	N	W-

	JFM	AMJ	JAS	OND
1977	N	N	N	W-
1978	W-	N	N	N
1979	N	N	N	N
1980	W-	N	N	N
1981	N	N	N	N
1982	N	W-	W	W+
1983	W+	W	N	C-
1984	C-	C-	N	C-
1985	C-	C-	N	N
1986	N	N	W-	W
1987	W	W	W+	W
1988	W-	N	C-	C+
1989	C+	C-	N	N
1990	N	N	W-	W-
1991	W-	W-	W	W
1992	W+	W+	W-	W-
1993	W-	W	W	W-
1994	N	N	W	W
1995	W	N	N	C-
1996	C-	N	N	N
1997	N	W	W+	W+
1998	W+	W	C-	C
1999	C+	C	C-	C
2000	C	C-	N	C-
2001	C-	N	N	N
2002	N	W-	W	W

Key

C = Cold
N = Neutral
W = Warm
C^- = Very Cold
W^- = Weakly Warm
C^+ = Strongly Cold
W^+= Strongly Warm

Annex 2 Recommended sowing window at the study sites

Site	Maize	Groundnuts	Cowpea	Sorghum
Chiredzi	1 Nov -Nov 19	20 Nov-Dec 10	20 Nov-Dec 10	Dec 1-dec 15
	20 Nov-Dec 10	Dec 11-Dec 31	Dec 11-Dec 31	Dec 16-dec 31
	Dec 11-Dec 31	Jan 1-Jan 15	Jan 1-Jan 15	Jan 1-jan 15
	Jan 1-Jan 15	Jan 16-Jan 31	Jan 16-Jan 31	Jan 16-jan 30
Bulawayo	20 Nov-Dec 10	Nov 1-Nov 19	20 Nov-Dec 10	Dec 1-dec 15
	15 Dec-31 Dec	20 Nov-Dec 10	Dec 11-Dec 31	Dec 16-dec 31
	1 Jan-15 Jan	Dec 11-Dec 30	Jan 1-Jan 15	Jan 1-jan 15
	16 Jan-Jan 30	Jan 1-Jan 20	Jan 16-Jan 31	Jan 16-jan 30
Harare	15 oct-31 cot	15 oct-31 oct	Nov 30-dec 15	Dec 1-Dec 10
	1 nov-16 Nov.	1 nov-16 Nov.	Dec 16-dec 30	Dec 11-Dec 30
	Nov 17-nov 30	Nov 17-nov 30	Jan 1-jan 15	Dec 31-jan 10
	Dec 1-dec 15	Dec 1-dec 15	Jan 16-jan 30	Jan 11-jan 30
Mt Darwin	Nov 1-Nov 19	Nov 1-Nov 19	Nov 30-dec 15	Dec 1-dec 15
	20 Nov-Dec 10	20 Nov-Dec 10	Dec 16-dec 30	Dec 16-dec 31
	Dec 11-Dec 31	Dec 11-Dec 31	Jan 1-jan 15	Jan 1-jan 15
	Jan 1-Jan 15	Jan 1-Jan 15	Jan 16-jan 30	Jan 16-jan 30
Gweru	Nov 1-Nov 19	Nov 1-Nov 19	Nov 30-dec 15	Dec 1-dec 15
	20 Nov-Dec 10	20 Nov-Dec 10	Dec 16-dec 30	Dec 16-dec 31
	Dec 11-Dec 31	Dec 11-Dec 31	Jan 1-jan 15	Jan 1-jan 15
	Jan 1-Jan 15	Jan 1-Jan 15	Jan 16-jan 30	Jan 16-jan 30
Masvingo	Nov 1-Nov 19	Nov 1-Nov 19	Nov 30-dec 15	Dec 1-dec 15
	20 Nov-Dec 10	20 Nov-Dec 10	Dec 16-dec 30	Dec 16-dec 31
	Dec 11-Dec 31	Dec 11-Dec 31	Jan 1-jan 15	Jan 1-jan 15
	Jan 1-Jan 15	Jan 1-Jan 15	Jan 16-jan 30	Jan 16-jan 30
Chivu	Nov 1-Nov 19	Nov 1-Nov 19	Nov 30-dec 15	Dec 1-dec 15
	20 Nov-Dec 10	20 Nov-Dec 10	Dec 16-dec 30	Dec 16-dec 31
	Dec 11-Dec 31	Dec 11-Dec 31	Jan 1-jan 15	Jan 1-jan 15
	Jan 1-Jan 15	Jan 1-Jan 15	Jan 16-jan 30	Jan 16-jan 30

Annex 3 Average Gross Margins (in $ '000) for different management strategies and ENSO phases at each study site a) Maize, b) Cowpea, c) Sorghum, d) Peanuts.

a) MAIZE			Long				Short			
	Site		W1	W2	W3	W4	W1	W2	W3	W4
ElNino	Boy	N18_sow	0.23	0.22	0.23	0.16	0.22	0.22	0.22	0.19
	Chiredzi	N18_sow	0.15	0.19	0.17	0.18	0.17	0.16	0.17	0.21
	Harare	N18_sow	0.30	0.27	0.27	0.28	0.26	0.26	0.27	0.28
	MT_Darwin	N18_sow	0.29	0.30	0.27	0.25	0.27	0.29	0.28	0.27
	Masvingo	N18_sow	0.22	0.19	0.17	0.18	0.22	0.21	0.20	0.17
	Gweru	N18_sow	0.24	0.22	0.23	0.24	0.25	0.24	0.24	0.26
LaNina	Byo	N18_sow	0.21	0.19	0.17	0.20	0.22	0.21	0.19	0.16
	Chiredzi	N18_sow	0.13	0.20	0.21	0.20	0.15	0.14	0.18	0.22
	Harare	N18_sow	0.21	0.29	0.28	0.28	0.24	0.27	0.28	0.28
	MT_Darwin	N18_sow	0.25	0.28	0.29	0.25	0.25	0.27	0.28	0.27
	Masvingo	N18_sow	0.25	0.25	0.21	0.18	0.23	0.24	0.23	0.22
	Gweru	N18_sow	0.18	0.21	0.23	0.24	0.21	0.21	0.21	0.25
Neutral	Byo	N18_sow	0.27	0.26	0.24	0.21	0.25	0.27	0.23	0.22
	Chiredzi	N18_sow	0.29	0.24	0.28	0.21	0.26	0.24	0.27	0.24
	Harare	N18_sow	0.28	0.30	0.30	0.30	0.26	0.27	0.29	0.29
	MT_Darwin	N18_sow	0.29	0.30	0.30	0.29	0.28	0.28	0.29	0.31
	Masvingo	N18_sow	0.28	0.30	0.26	0.19	0.27	0.29	0.29	0.24
	Gweru	N18_sow	0.24	0.25	0.27	0.27	0.21	0.26	0.26	0.25

b) COWPEA			Long				Short			
	Site		W1	W2	W3	W4	W1	W2	W3	W4
ElNino	byo	N18_sow	1.38	1.22	0.98	0.64	0.97	0.89	0.82	0.60
	Chiredzi	N18_sow	0.37	0.28	0.38	0.81	0.17	0.14	0.12	0.25
	Harare	N18_sow	1.91	1.66	1.40	0.91	1.64	1.31	1.14	1.00
	MT_Darwin	N18_sow	2.08	1.80	1.13	0.73	1.25	1.23	0.97	0.61
	Masvingo	N18_sow	0.91	1.05	0.68	0.54	0.69	0.86	0.65	0.56
	Gweru	N18_sow	1.45	1.24	1.00	0.29	1.39	1.05	0.95	0.48
LaNina	byo	N18_sow	1.33	1.17	0.98	0.64	0.87	0.84	0.86	0.64
	Chiredzi	N18_sow	0.30	0.34	0.47	0.35	0.19	0.12	0.18	0.31
	Harare	N18_sow	1.84	1.64	1.24	0.59	1.17	1.27	1.21	0.77
	MT_Darwin	N18_sow	1.67	1.42	1.21	0.54	1.01	1.01	0.91	0.56
	Masvingo	N18_sow	1.31	1.36	0.92	0.47	0.86	1.00	0.84	0.55
	Gweru	N18_sow	1.37	0.94	0.56	0.19	1.34	0.88	0.65	0.32
Neutral	byo	N18_sow	1.39	1.75	1.54	1.01	0.95	1.26	1.23	0.95
	Chiredzi	N18_sow	0.66	0.42	0.92	0.49	0.31	0.24	0.49	0.43
	Harare	N18_sow	2.81	2.48	1.55	0.79	2.13	2.02	1.66	1.17
	MT_Darwin	N18_sow	2.15	1.91	1.82	1.14	1.30	1.24	1.12	0.96
	Masvingo	N18_sow	1.81	1.61	1.27	0.63	1.24	1.18	1.17	0.69
	Gweru	N18_sow	2.12	1.63	0.71	0.27	1.79	1.64	0.99	0.44

c) SORGHUM			long				short			
			W1	W2	W3	W4	W1	W2	W3	W4
ElNino	byo	N18_sow	0.32	0.31	0.26	0.10	0.32	0.30	0.30	0.28
	Chiredzi	N18_sow	0.33	0.26	0.24	0.17	0.27	0.24	0.24	0.27
	Harare	N18_sow	0.18	0.23	0.23	0.05	0.30	0.34	0.35	0.37
	MT_Darwin	N18_sow	0.26	0.38	0.37	0.33	0.34	0.35	0.36	0.36
	Masvingo	N18_sow	0.29	0.23	0.24	0.17	0.29	0.26	0.25	0.26
	Gweru	N18_sow	0.12	0.08	0.04	-0.04	0.33	0.32	0.33	0.15
LaNina	byo	N18_sow	0.17	0.26	0.14	0.03	0.24	0.24	0.26	0.23
	Chiredzi	N18_sow	0.24	0.32	0.33	0.37	0.23	0.22	0.28	0.33
	Harare	N18_sow	0.33	0.35	0.28	0.12	0.34	0.36	0.37	0.31
	MT_Darwin	N18_sow	0.36	0.36	0.39	0.32	0.33	0.33	0.37	0.37
	Masvingo	N18_sow	0.31	0.24	0.25	0.23	0.33	0.25	0.24	0.27
	Gweru	N18_sow	-0.01	0.13	0.07	-0.02	0.33	0.28	0.31	0.18
Neutral	byo	N18_sow	0.31	0.36	0.30	0.14	0.29	0.32	0.31	0.31
	Chiredzi	N18_sow	0.41	0.33	0.47	0.27	0.33	0.34	0.39	0.33
	Harare	N18_sow	0.32	0.27	0.36	0.13	0.33	0.35	0.37	0.39
	MT_Darwin	N18_sow	0.25	0.37	0.38	0.39	0.34	0.34	0.36	0.38
	Masvingo	N18_sow	0.35	0.37	0.41	0.32	0.34	0.35	0.38	0.40
	Gweru	N18_sow	0.18	0.16	0.01	-0.08	0.33	0.31	0.32	0.28

d) PEANUTS			long				short			
			W1	W2	W3	W4	W1	W2	W3	W4
ElNino	byo	N18_sow	0.41	0.44	0.46	0.46	0.50	0.50	0.50	0.42
	Chiredzi	N18_sow	0.25	0.33	0.35	0.37	0.28	0.37	0.37	0.36
	Harare	N18_sow	0.37	0.43	0.50	0.52	0.56	0.61	0.65	0.66
	MT_Darwin	N18_sow	0.33	0.43	0.48	0.50	0.47	0.54	0.54	0.53
	Masvingo	N18_sow	0.35	0.36	0.39	0.45	0.44	0.42	0.42	0.42
	Gweru	N18_sow	0.48	0.45	0.50	0.51	0.56	0.52	0.47	0.41
LaNina	byo	N18_sow	0.33	0.39	0.41	0.41	0.44	0.45	0.41	0.35
	Chiredzi	N18_sow	0.33	0.32	0.41	0.43	0.44	0.40	0.48	0.41
	Harare	N18_sow	0.32	0.47	0.51	0.53	0.51	0.59	0.63	0.60
	MT_Darwin	N18_sow	0.37	0.42	0.47	0.51	0.51	0.55	0.55	0.54
	Masvingo	N18_sow	0.41	0.35	0.40	0.43	0.54	0.44	0.44	0.40
	Gweru	N18_sow	0.41	0.45	0.46	0.39	0.48	0.47	0.41	0.32
Neutral	byo	N18_sow	0.37	0.43	0.48	0.52	0.49	0.51	0.51	0.50
	Chiredzi	N18_sow	0.33	0.54	0.45	0.40	0.42	0.62	0.47	0.48
	Harare	N18_sow	0.41	0.47	0.53	0.58	0.66	0.68	0.71	0.72
	MT_Darwin	N18_sow	0.33	0.41	0.48	0.56	0.52	0.55	0.62	0.64
	Masvingo	N18_sow	0.43	0.49	0.54	0.60	0.59	0.59	0.59	0.59
	Gweru	N18_sow	0.42	0.49	0.51	0.50	0.50	0.51	0.47	0.41

Annex 4 Maximum Average Gross Margins (in $ '000) for and ENSO phases at each study site.

Maximum Gross Margin by ENSO State

		maize		cowpea		sorghum		peanuts	
		long	short	long	short	long	short	long	short
ElNino	byo	0.23	0.22	1.38	0.97	0.32	0.32	0.44	0.50
	Chiredzi	0.19	0.21	0.81	0.25	0.33	0.27	0.33	0.37
	Harare	0.30	0.28	1.91	1.64	0.23	0.37	0.43	0.66
	MT_Darwin	0.30	0.29	2.08	1.25	0.38	0.36	0.43	0.54
	Masvingo	0.22	0.22	1.05	0.86	0.29	0.29	0.36	0.44
	Gweru	0.24	0.26	1.45	1.39	0.12	0.33	0.48	0.56
LaNina	byo	0.21	0.22	1.33	0.87	0.26	0.26	0.39	0.45
	Chiredzi	0.21	0.22	0.47	0.31	0.37	0.33	0.33	0.48
	Harare	0.29	0.28	1.84	1.27	0.35	0.37	0.47	0.63
	MT_Darwin	0.29	0.28	1.67	1.01	0.39	0.37	0.42	0.55
	Masvingo	0.25	0.24	1.36	1.00	0.31	0.33	0.41	0.54
	Gweru	0.24	0.25	1.37	1.34	0.13	0.33	0.45	0.48
Neutral	byo	0.27	0.27	1.75	1.26	0.36	0.32	0.43	0.51
	Chiredzi	0.29	0.27	0.92	0.49	0.47	0.39	0.54	0.62
	Harare	0.30	0.29	2.81	2.13	0.36	0.39	0.47	0.72
	MT_Darwin	0.30	0.31	2.15	1.30	0.39	0.38	0.41	0.64
	Masvingo	0.30	0.29	1.81	1.24	0.41	0.40	0.49	0.59
	Gweru	0.27	0.26	2.12	1.79	0.18	0.33	0.49	0.51

Best Growing Window By ENSO State

		maize		cowpea		sorghum		peanuts	
		long	short	long	short	long	short	long	short
ElNino	byo	1	3	1	1	1	1	2	1
	Chiredzi	2	4	4	4	1	1	2	2
	Harare	1	4	1	1	3	4	2	4
	MT_Darwin	2	2	1	1	2	4	2	3
	Masvingo	1	0	2	2	1	1	2	1
	Gweru	4	4	1	1	1	3	1	1
LaNina	byo	1	0	1	1	2	3	2	2
	Chiredzi	3	4	3	4	4	4	1	3
	Harare	2	4	1	2	2	3	2	3
	MT_Darwin	3	3	1	2	3	3	2	3
	Masvingo	2	2	2	2	1	1	1	1
	Gweru	4	4	1	1	2	1	2	1
Neutral	byo	1	2	2	2	2	2	2	3
	Chiredzi	1	3	3	3	3	3	2	2
	Harare	3	3	1	1	3	4	2	4
	MT_Darwin	3	4	1	1	4	4	2	4
	Masvingo	2	2	1	1	3	4	2	3
	Gweru	3	3	1	1	1	1	2	2

Maximum Gross Margin Without ENSO Information

	maize		cowpea		sorghum		peanuts	
	long	short	long	short	long	short	long	short
byo	0.24	0.24	1.42	1.02	0.32	0.30	0.42	0.49
Chiredzi	0.21	0.22	0.60	0.32	0.33	0.30	0.37	0.44
Harare	0.29	0.28	2.15	1.65	0.28	0.36	0.45	0.66
MT_Darwin	0.30	0.28	1.99	1.19	0.38	0.37	0.42	0.57
Masvingo	0.25	0.25	1.35	1.02	0.32	0.32	0.40	0.51
Gweru	0.25	0.25	1.65	1.51	0.12	0.33	0.46	0.52

Best Growing Window Without ENSO Information

	maize		cowpea		sorghum		peanuts	
	long	short	long	short	long	short	long	short
byo	1	2	2	2	2	3	2	2
Chiredzi	3	4	4	4	3	4	2	2
Harare	4	4	1	1	3	3	2	3
MT_Darwin	2	4	1	1	3	4	2	4
Masvingo	1	2	1	2	1	1	2	1
Gweru	4	4	1	1	2	1	2	1

Annex 5 – Pivot Table and Chart of Average Gross Margin for the different management strategies

Location	MT_Darwin
crop	maize
Cultivar	short
Enso Class	LaNina

Average of GM$('000)	Window			
N_Applic	1	2	3	4
N0_sow	0.12	0.11	0.13	0.16
N9_sow	0.20	0.20	0.21	0.22
N9_late	0.20	0.20	0.21	0.22
N18_sow	0.25	0.27	0.28	0.27
N18_late	0.26	0.27	0.28	0.27